EFFECT OF CONSTRUCTION DUST ON PATIENTS AND WORKERS HEALTH: A QUANTITATIVE RISK ANALYSIS

A Thesis

by

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ABSTRACT

Nomosocial infections kill a significant number of medical patients each year in the USA. Previous study has led to a series of studies into the intrusion of dust from any source into patient areas in hospitals. The goal of the overall research work is to ultimately reduce the mortality rates.

This specific study looks to investigate the movement of air around doorways inside a building of similar configuration to the hospital. The specific goal is to determine if the door velocities are sufficient to allow the movement of dust and lighter particles beneath and around doors. No distinction is made in this study as the dust source.

The hypothesis is that door velocities are insufficient to move dust particles with a size of 1 micrometer. The test method involved measurement of the door air gaps and the air velocity for a set of typical doors in the Langford Building A at Texas A&M University.

The hypothesis is false and a closed door does not prevent the movement of air, which at Langford was measured to a velocity of 3.5 meters per second. Future work should look to measure the actual movement mass of air and dust beneath and around doors.

DEDICATION

To the constant love and support I have received from my family back in India: Mrudula Bhatt, Manish Bhatt, Manisha Bhatt and Akshal Bhatt. Especially to my late grandfather Himmat Bhatt.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr John Nichols: you are one of the best person I have ever come across in my entire life. I would also like to thank my co-chair, Dr Kevin Glowacki, and committee member Assistant Dean Leslie Feigenbaum, for their guidance and support throughout the course of this research.

A special note of thanks to Katy for being there for me. Anuj sir, Biren sir, Bhavik, Nipur, Sagar (both) and Saumya, this degree wouldn’t have been possible without you all. I am also thankful to each soul which touched my life in a good or a bad way making it a memory or a lesson.

NOMENCLATURE

AIA	American Institute of Architects
APIC	Association for Professionals in Infection Control
CDC	Center for Disease Control and Prevention
HVAC	Heating, Ventilation and Air Conditioning
FFT	Fast Fourier Transform
DFT	Discrete Fourier Transform

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CHAPTER I

INTRODUCTION

INTRODUCTION

Hospitals are typically one of the most complex facilities to build given the critical nature of its occupant's health or the need to maintain an adequate supply of healthy medical personal. There are many ways that people may die in hospitals, natural causes, earthquakes and nomosocial infections to identify three simple causes.

Bassett (2013) can be identified as the clear starting point for this research work, her first study looked at the simple yet interesting question as to whether a plastic barrier was sufficient to prevent the spread of dust and the associated infection agents from a construction area into a patient area at a hospital. She showed that the barrier was sufficient. This work has been extended by others. Reboux et al. (2014) provided a decade long study of Aspergillosis deaths in a French hospital, Nichols (2015) undertook a detailed statistical study of the French data and showed that a number of peaks existed in the death toll Fast Fourier Transform data. The two month peak is of current interest due to the likely impact of the air conditioning system on this fatality set.

In any long running study there are numerous aspects of the engineering and physics to be investigated as the overarching problem is reduced in a set of manageable steps. This simple step is to look at the movement of air around door gaps in an air conditioned building to determine if sufficient velocities exist to move dust and infection agents.

Even with technological advancements in the field of healthcare and construction, recent reports show an increase in the number of in-house patient who contract nosocomial infections, which are often fatal. A percentage of these infections are directly or indirectly causes by dust from construction activities (Reboux et al., 2014). Most vulnerable to these infections are the patients who are within the facility for treatment of their pre-existing ailments who often have compromised immune system. Figure 1 shows the Aspergillosis fatality counts for the United States for the period 1992 to 2006.

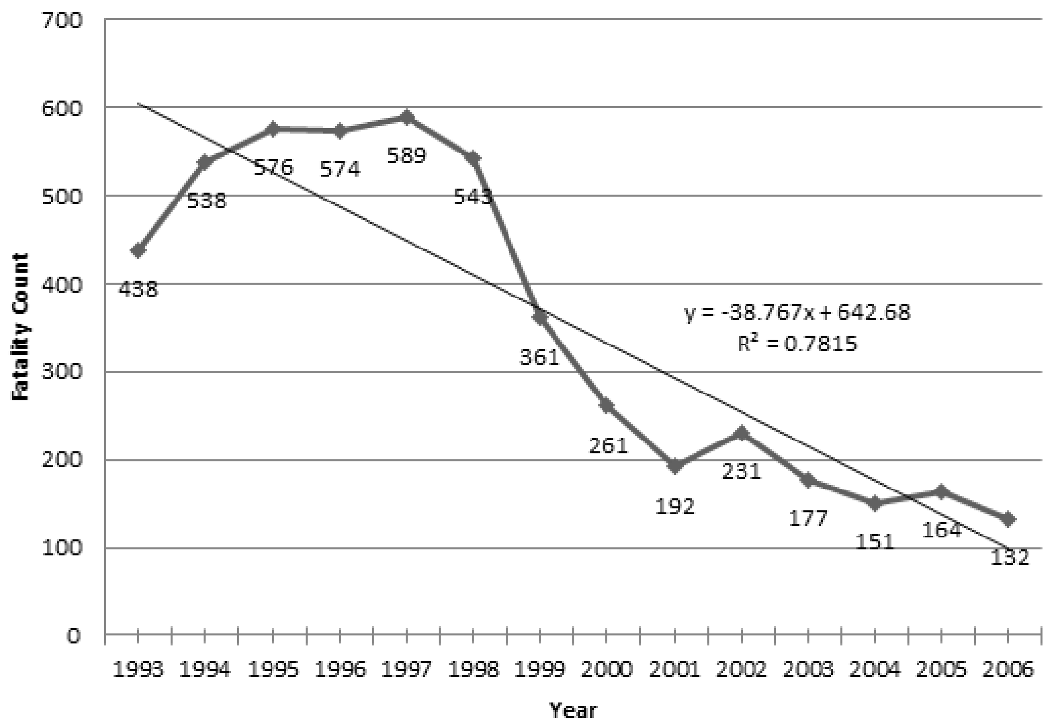

Figure 1. Aspergillosis fatalities - 1993 - 2006 in the USA after Bassett (2013)

This chapter summarizes the problem statement, hypothesis and limitations. The research significance is outlined. The thesis outlines the hypothesis, study methods, results and provides a conclusion for the study.

PROBLEM STATEMENT

A study of the potential movement of dust and infection agents in the spaces between closed doors and walls is of interest to hospital designers and to the long running research study on dust in construction at TAMU.

HYPOTHESIS

The air velocity around closed doorways in the Langford Architectural Building A is not sufficient to move one micrometre dust beneath the door.

LIMITATIONS

The research limitations are:

- the velocity of air is considered, but not its direction
- there is no way to determine the amount of fungus that is being carried by the air
- air is not the only avenue for entry for the infectious particles
- visitors who come and visit and employees are also carriers of the particles in their clothing, shoes or other accessories
- The limitations of Bernoulli's equation apply to the analysis

RESEARCH SIGNIFICANCE

Reduce mortality rates in hospitals from nomosocial infections.

CHAPTER II

LITERATURE REVIEW

INTRODUCTION

This literature review considers the source of the infections, infection and mortality rates, healthcare spending, typical hospital project scope, prior research, air circulation, air velocity and pressure, sample room and summary.

Figure 2 shows a spore of fungus that can cause illness in immune compromised patients.

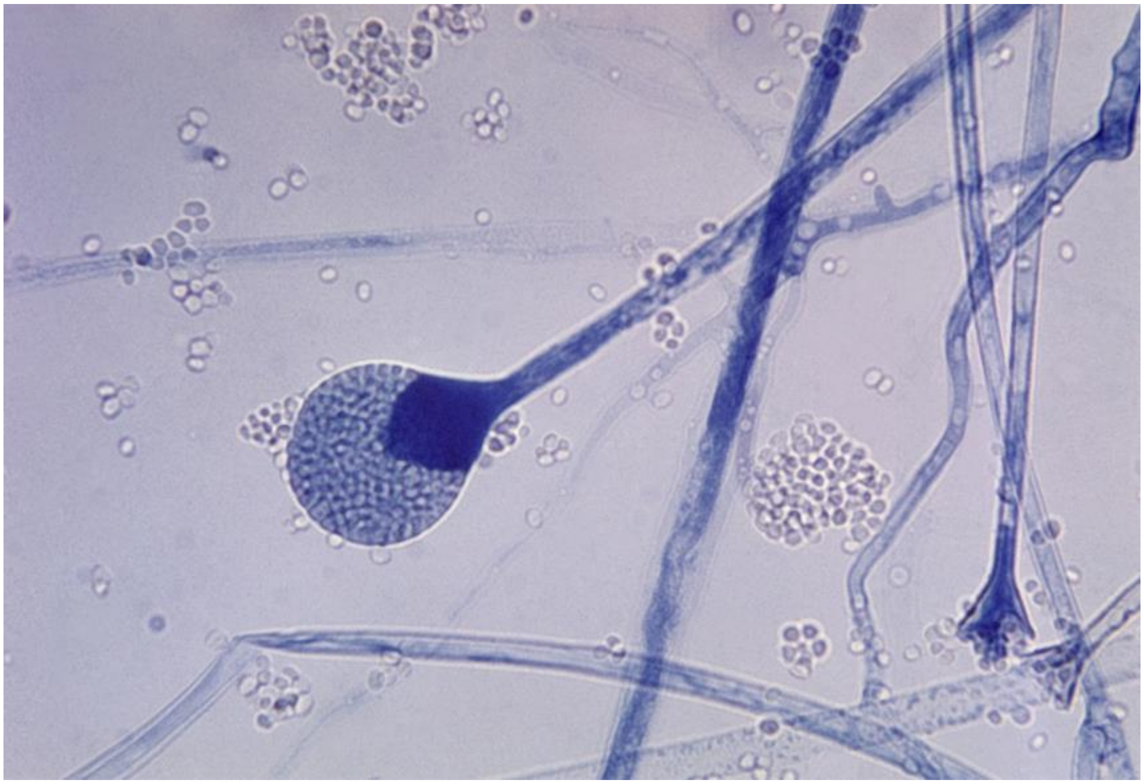

Figure 2. A sporangium of a Mucoralean fungus from Centers for Disease Control and Prevention (2012a)

INFECTION SOURCE

Aspergillus is a dangerous microorganism which causes acute infection. It has continued to be a challenge to healthcare officials and should be addressed as a matter of urgency.

Aspergillus is a group of around 200 known fungi and most of its family are known to be detrimental to human health. Nearly half of the deaths caused by this fungus were construction related according to CDC. Overberger (1995) note the growth of fungi and mould in wet and damaged areas. Health-care–associated opportunistic infections are members of the order of Mucorales and miscellaneous moniliaceous mould. Some fungi are airborne pathogens.

The United States people spend more than $859 Billion in a total of 5686 hospital facilities or about $2500 per person or $10,000 for a family of four according to American Hospitals Association. Yet, the US has still a high incidence of Aspergillus infections. Most of the patients who were affected were already suffering from cancer, pulmonary disorder, organ transplant or AIDS, which makes this all the more challenging. Most vulnerable to this infection are the workers and patients who are suffering with deficient immune systems—i.e., transplantation of stem cell, chemotherapy for cancer, or AIDS. The

Reboux et al. (2014) looks at the rates of fungi infections in a hospital setting. The likely sources of this infection are:

- air borne
- human infection vectors

- dust from the environment and construction activities
- failure of mechanical systems

Clearly, the construction activites should not raise the mortality rate, but they do.

INFECTION AND MORTALITY RATES

Aspergillus spores have a size of two to three microns, and attach to dust they form particles as large as 25 microns (Malik, 2008). As medicine has improved the survival rates of people affected by serious diseases invariably fatal prior to 1970.

Table 1 shows the incidence and range of rates for patients with a variety of transplant types who suffer from fungal infections. The table data taken from Singh (2005) summarizes

- incidence range both low and high
- average values
- mean days to onset

Nichols (2015) showed a two month cycle in the fungal infections in the French hospital study. A preliminary review of the likely causes of the two month cycle strongly suggests a mechanical failure cause, probably related to filters and filter changing.

Figure 3 shows the rate of fungal infections in some types of transplant patients in the USA. Allogeneic stem cell has the highest rate at 26 per-cent.

Table 1.

Characteristics of invasive Aspergillosis in transplant recipients – part 1 – from Singh (2005)

Type of transplant	Incidence Range Low %	Incidence Range High %	Average Range	Mean Days to Onset
Liver	1	8	2	17
Lung	3	14	6	120
Heart	1	15	5.2	45
Kidney	0	4	.7	82
Pancreas	1.1	2.9	-	NA
Small bowel	0	10	2.2	66
Allogeneic stem cell	5	26	10	27-30
Autologous stem cell	2	6	4.8	10-20
Non-myeloblative stem cell	8	23	11	34

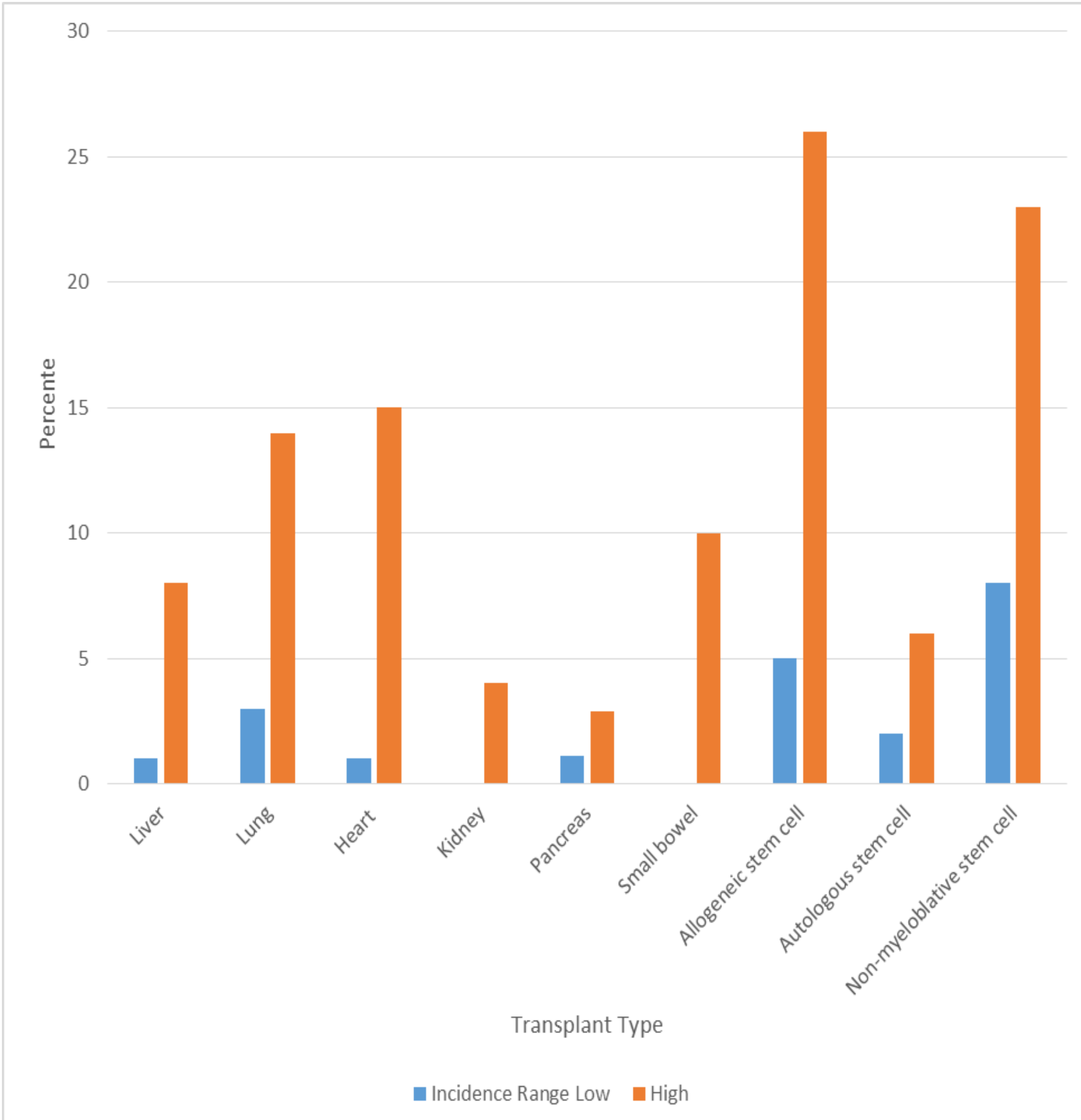

Figure 3. Incidence of fungal infections in transplant patients

Table 2 shows the second part of the Singh data. This table provides

- range both low and high from Aspergillosis
- mortality rates
- mean days to onset

Table 2.

Characteristics of invasive Aspergillosis in transplant recipients – part 2 – from Singh (2005)

Type of transplant	**Percent due to disseminated Aspergillosis Low**	**Percent due to disseminated Aspergillosis High**	**Mortality percentage High**
Liver	50	60	87
Lung	15	20	68
Heart	20	35	78
Kidney	9	36	77
Pancreas	NA	NA	100
Small bowel	66	66	66
Allogeneic stem cell	27	30	92
Autologous stem cell	10	20	92
Non-myeloblative stem cell	34	34	67

Figure 4 shows the average days till the onset of the illness. The graph also shows the average time between filters, assuming an average stay for transplant patient of at least 30 days, a high percentage of patients are likely to experience a two month cycle of infections.

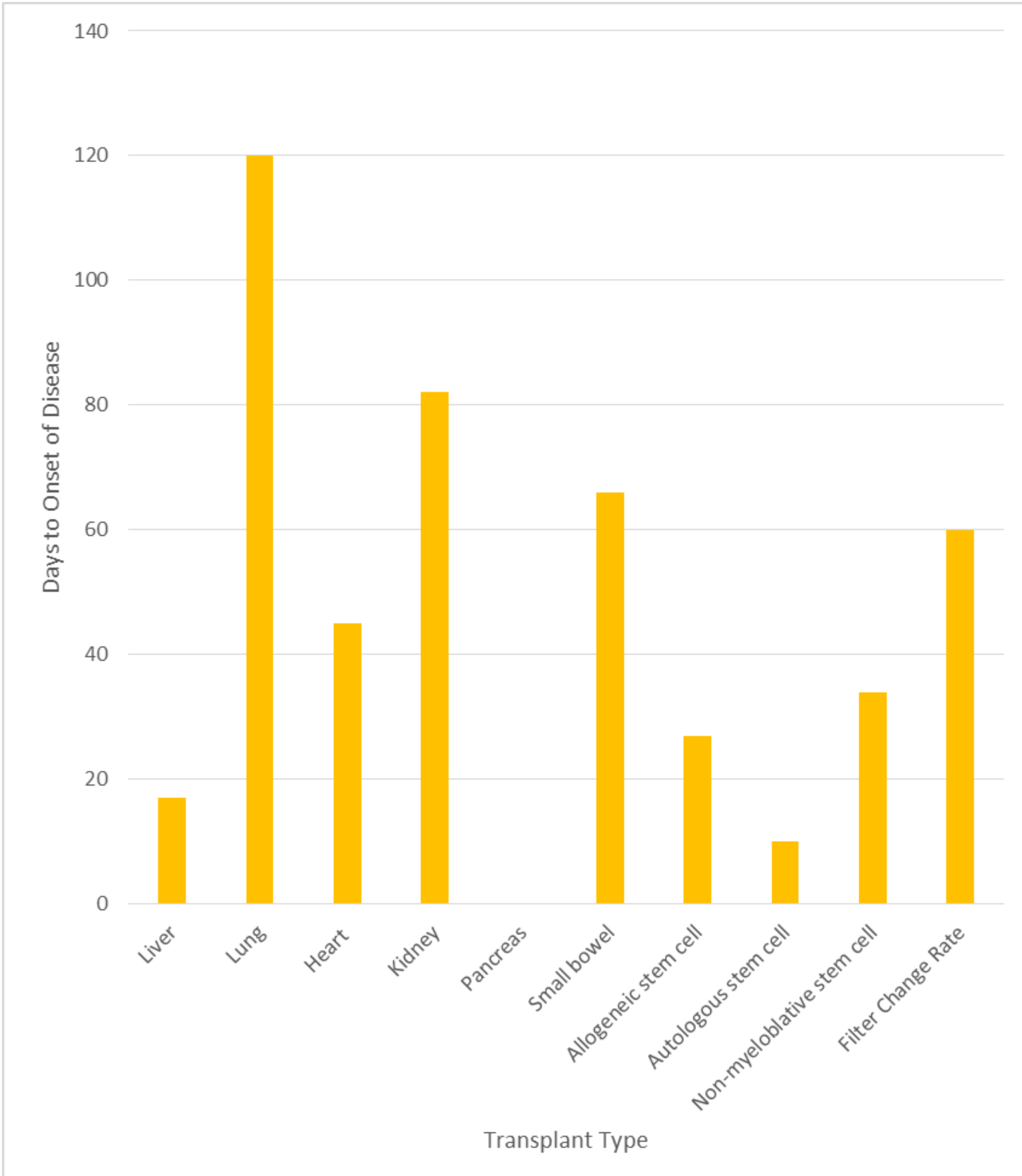

Figure 4. Days till onset of the disease

HEALTH CARE SPENDING

Around $10 billion each year is spent in healthcare construction out of which 70% is used in renovation and 30% for new construction.

Two million infections are contracted by patients each year in hospitals to people who are already under treatment for complex and expensive treatment, 88,000 die unfortunately according to the CDC, (Centers for Disease Control and Prevention, 2012a, 2012b, 2013, 2014)

Riley, Freihaut, Bahnfleth, and Karapatyan (2004) notes that designers, facility managers, architects, engineers and construction managers should be responsibly educated about how renovation and construction projects can negatively affect the air quality for patients

TYPICAL HOSPITAL PROJECT SCOPE

Francis, Egbu, and Gibb (2003) present a case study about the investment required for a major hospital with 1000 bed capacity. Table 3 lists the data from the Francis paper. These statistics explain the magnitude of financial investment being made in major healthcare projects. The community expects value for this type of investment. Quality assurance becomes one of the key aspects which needs to be emphasized by a Construction Manager.

Table 3.

Typical major hospital project details

	Requirement	Capacity required or money spent
1	Approx. Bed Capacity	1,000
2	Site Size: 25 ha	63 acres on Greenfield location
3	Car Parking	2,300
4	Entrance (access into facility)	11
5	Rooms	3500
6	Internal doors	4800
7	Windows	1,640
8	Light	13,320
9	Suspended Ceiling	76,000 m2
10	Vinyl flooring	59,000 m2
11	Operating theatres	23
12	Water pipe work	64,000
13	Development Cost	$330 million
14	Electric cabling	1,200 km
15	Trees	16,000
16	Shrubs	50,000
17	Shelving	8,000 m run
18	Developed phase	47 months

Sehulster and Chinn (2003) layout the required involvement of infection-control personnel in all phases such as demolition, construction and renovation of Healthcare facilities. This would include risk assessment of construction barriers according to its types, daily monitoring and documenting the negative airflow in construction or renovation area.

Linders Health Institute (2015) is one of the many companies who have started to layout their own set of practice guidelines in ICRA/PCRA training courses. It offers education to Construction Managers, Project Managers, Architects, Engineers, Contractors, HVAC and Legal personnel. Primary focus of this group is Construction in Healthcare and the best practices to be followed in it. They have online courses which enable a company to subscribe and educate staff in best practices.

According to a study, it is very important that the construction team evaluates the effects of construction and its implications on the patients being treated at the facility (Lee, 2010). Renovation and retrofitting follow this doctrine as well as new construction. The pre-construction risk assessment (PCRA) which is conducted will in turn aid in the preparation of the evaluation for the infection control risk assessment (ICRA).

PCRA would help in bringing the factors which affect the construction together, in this type of study utmost importance is to be given to life safety and infection control. Vibration, quality of the air inside the facility, noise, emergency services and hazard causing material should be accounted for while analyzing the conditions and further advancing the research for this type of study.

PRIOR RESEARCH

Bassett (2013) conducted a study where barrier systems were used to test for blocking of particles. The hypothesis of the test measured whether the plastic sheet barrier system maintains its barrier by analyzing how many particles are actually transmitted through the system using a filter to catch the outbound particles of powder. The research showed that these barriers are highly efficient in stopping the entry of unwanted dust, in this case modelled using talc powder.

The solution to air flowing into the hospital is HEPA filters. HEPA stands for High Efficiency Particulate Air, in some cases these include high-energy ultraviolet light units to kill off the live bacteria and viruses. We have been able to achieve a 99.99% success rate in stopping the entry of microorganisms of sizes ranging to 0.12 microns through the HVAC system.

AIR CIRCULATION

The air currents within the facility has the potential to transport bacteria, virus and other infectious microorganisms which can affect the health of the staff, patients and visitors adversely. Generally a standard ventilated single room would have 6 (six) air changes by its ventilation system which would introduce fresh air into the environment within the building (Weston, 2008).

The exchange of air also takes place by the gaps presents on the sides, above and below the door. Sometimes these gaps are the avenues by which the air in the corridor and the room gets mixed causing the influx of infections in the room. This infection source is also a problem faced by patients who have very low immunity and are undergoing isolation.

AIR VELOCITY AND PRESSURE

Figure 5 shows the basic system for the analysis of the flow of air within the air conditioning system.

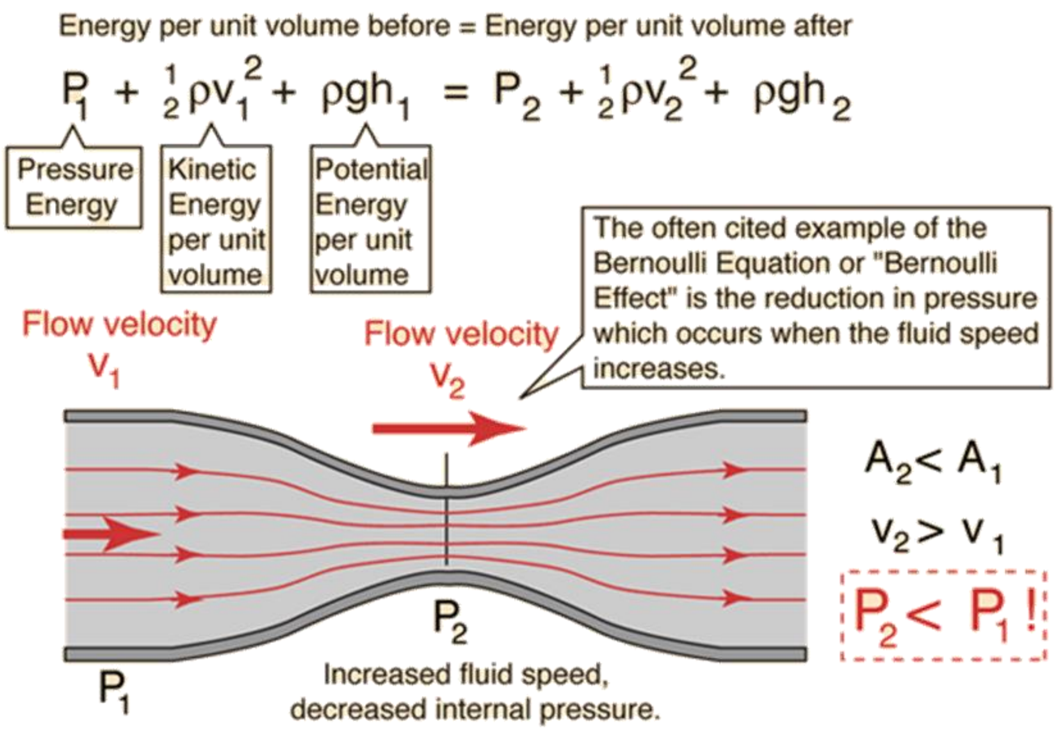

Figure 5. Bernoulli's equation from HyperPhysics (2000)

A hospital unlike a controlled system, has numerous air paths which affect the velocity and pressure that will occur inside the room and the corridor. A study looking at this is being completed by (Cheng, 2016). The airflow from the gaps in doors would also be affected by various factors like the air flow in the room, the air flow in the corridor, the ventilation in the room and the ventilation in the corridor.

In an ideal system for hospitals, the pressure in the room should be maintained such that the air flow is from within the room to outside (in the corridor). But quite often it is the other way round or in some cases it is cyclical or random which should raise a concern of what type of a facility we are building for the patients.

Air flow into a building occurs because of the difference in pressure between the part of a building in a windstorm and the internal pressure in a room, from a variety of causes including

- flow from the air conditioning system
- flow from doors
- flow from windows
- internal recirculation

. There are standard methods of analysis used to consider the problem and the solutions to the problem. The starting point for the analysis is Euler's equation of motion long a streamline. Euler's equation (Streeter, 1979) for flow along a stream line can be expressed as shown in equation (1) shows

$$\frac{1}{\rho}\frac{\partial p}{\partial s} + g\frac{\partial z}{\partial s} + v\frac{\partial v}{ds} + \frac{\partial v}{\partial t} = 0 \qquad (1)$$

Figure 6 shows the definition sketch for this equation.

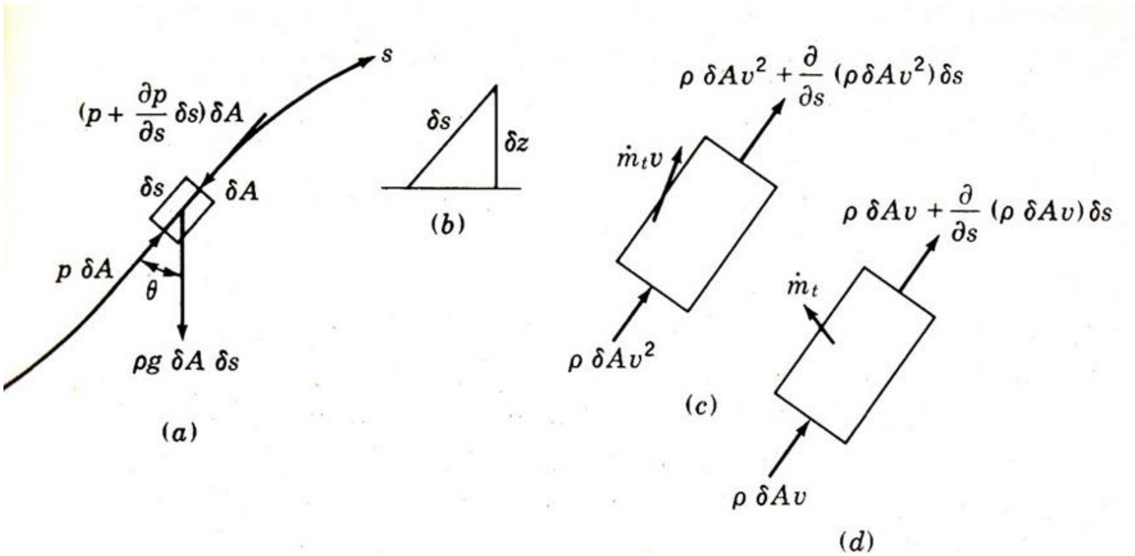

Figure 6. Definition sketch for Euler's equation from Streeter (1979)

The interesting issue with all fluid flow problems is the simplifying assumptions that need to be made to provide a tractable solution to the problem being studied with Euler’s equation. A simple assumption is a barotopic equation of state as shown in equation (2).

$$\rho = \rho(p) \tag{2}$$

Integration of equation (1) for a constant density provides the well-known Bernoulli equation (3)

$$K = \frac{p}{\rho}\left(\frac{\gamma}{\gamma - 1}\right) + gz + \frac{v^2}{2} \tag{3}$$

Each of the terms of the Bernoulli equation represents an energy term. In air flow the change in elevation, z , is assumed to be negligible given the relative density of air and assuming flow along a stream line so that K is constant implies:

$$z_1 + \frac{p_1}{\gamma} + \frac{v_1^2}{2g} = z_2 + \frac{p_2}{\gamma} + \frac{v_2^2}{2g} \tag{4}$$

Further future research will look in detail at the air conditioning and computational fluid dynamics problems related to a real building. Let us make a simple assumption that a wind is causing pressure on the windward side of a building that provides a potential inflow into an open or opening door. The pressure on the wall of the barrier increases as the velocity in the region reduces, essentially creating a high pressure eddy in the flow. The equation for estimating the pressure on the wall is:

$$p_1 - p_0 = \frac{1}{2} C \rho (v_1^2 - v_0^2) \tag{5}$$

In the case of an eddy at the front of the building, v_0 is zero. In terms of the internal pressure, J. D. Holmes (1994) provides a fairly conventional dimensional analysis of although he does not derive the dimensional analysis in full.

The π theorem provides

$$F(A_1, A_2, A_3 ... A_n) = 0 \tag{6}$$

Where π_1, π_2 are dimensional groups for the A_i quantities. J.D. Holmes (2001) appears to suggest that

$$F(A, \mathrm{V}_0, p_0, \frac{1}{2} \rho_a U^2, \mu, l_u, \sigma_u) = 0 \tag{7}$$

Five non-dimensional parameters are derived by Holmes from this set of variables and constants. Cheng (2016) outlines the space syntax concepts that will prove central to the solution of this problem. Glowacki and others have developed the basis for space syntax analysis (K.T. Glowacki, 2015; K. T. Glowacki & Dafedar, 2010).

Henderson and Wooding (1964) provide the start of the analysis for mass within a simple system for this case of overland flow, the analogy can be extended to air mass movement. Field and Williams (1987) application to two dimensional overland flow can be directly extended to the hospital problem using the technique developed by (J.D. Holmes, 2001). There is a long way to go on this research but it appears potentially productive.

In the simplest terms, the quantity of interest is the response time for the air pressure to reasonably stabilize after an opening occurs between the region of external and internal pressure. This simple calculation was recently completed for others,

This equation (8) provides a balance between the rate of inflow of air into the room and the rate of increase of pressure or density inside the room.

$$\rho_i Q = (\frac{d\rho_i}{dt})V_0 \tag{8}$$

Let us assume that an opening such as a door acts as an orifice, which allows for the reality of air flow which is not laminar or inviscid, as shown in equation (9)

$$Q = kA\sqrt{\frac{2(p_e - p_i)}{\rho_a}} \tag{9}$$

The standard assumption in engineering is an adiabatic flow law which provides a functional relationship between the internal pressure and density as shown in equation (10)

$$\frac{p_i}{\rho_i^{\gamma}} = c \tag{10}$$

Although it should be clearly understood that for the range of pressures and densities encountered in the world's weather, this equation can be approximated using a first order polynomial, substitute (8) and (9) into (10) and integrate to establish (11)

$$t = \frac{\rho_0 V_0 U}{\gamma k A p_0} \sqrt{C_{pe} - C_{pio}} \tag{11}$$

Rearranging with (8) yields:

$$Q = (\frac{d\rho_i}{dt}) V_0 \frac{1}{\rho_i} \tag{12}$$

Future research should meld the Field Williams Model, space syntax and the work of Holmes into a single model for hospital air mass movement. This is not a trivial task.

SAMPLE ROOM

As an example, let us assume an opening occurs into a room, such as around a door. Let us assume for simplicity that the opening acts like a pipe with an equivalent diameter, from the computer FORTRAN program, RK2, developed to solve equation (12), the response time for a room to settle from a change in the relative differential pressure from the outside to the inside of the room can be calculated directly. Figure 7 shows the solution for a room in a typical house.

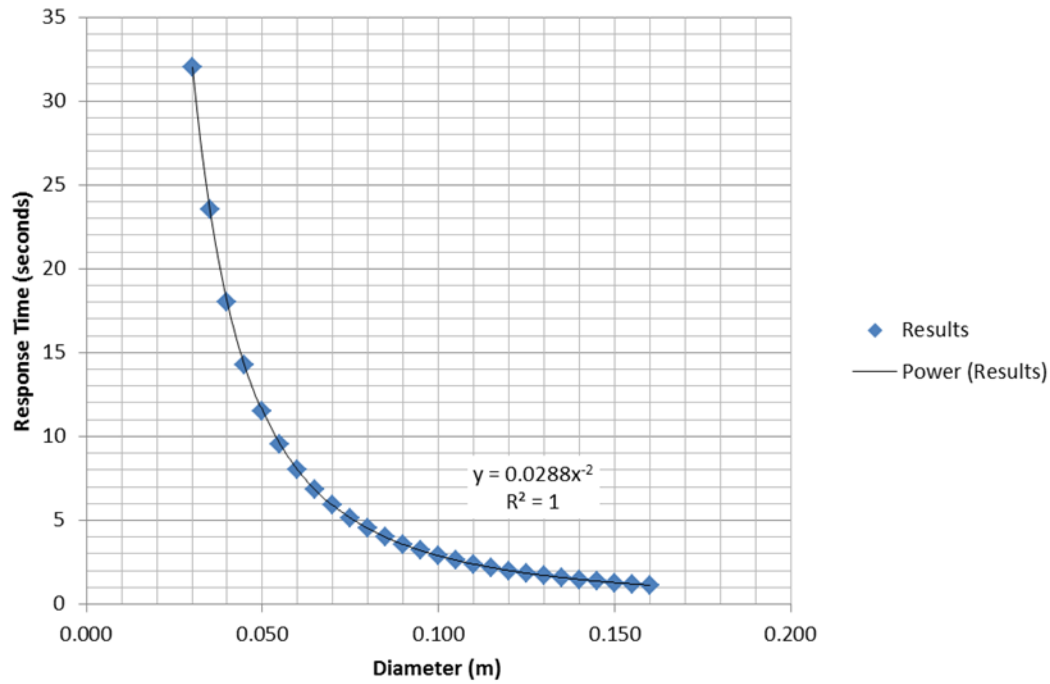

Figure 7. Response time for typical room with differential pressure

The point of this analysis is to demonstrate the problem is tractable.

SETTLEMENT RATE FOR DUST

Dust settles if suspended in air. The rate of settlement is controlled by Stokes Law. The applicable equation for settlement of particles in dry air is given in equation (13):

$$V = \frac{2r^2(\rho_s - \rho_a)g}{9\mu} \tag{13}$$

Where V is the velocity in m/s, r is the radius of the dust particle, g is 9.806 m/s. μ is the viscosity of the air, ρ_s is the density of the solid and ρ_a is the density of the air. A simple FORTRAN program was developed to determine the settling velocity for different sized talc particles in air using Stokes Law. The Reynolds number for the settlement of Talc powder in air was less than one, therefore the flow is laminar and Stokes law holds.

Figure 8 shows the settling velocity for the particle diameter range of 1 to 10 micrometers.

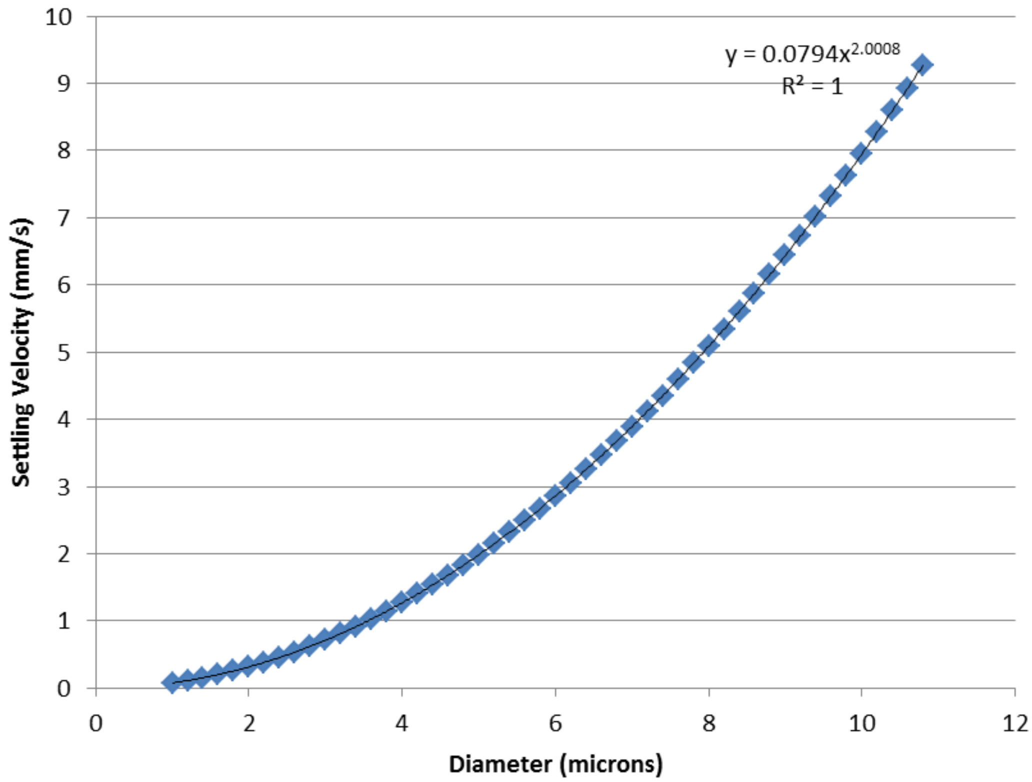

Figure 8. Stokes Law - settling velocities - talc

SUMMARY

There is a long research road ahead to understand how fungi get into rooms, this literature review touches on some of the issues and provides some pointer to the future.

CHAPTER III

METHODOLOGY

INTRODUCTION

This chapter summarizes the methods used for the experimental work. A typical building of the size observed in regional hospitals was selected for testing for the air velocity and pressures.

Two test protocols were used for the experimental work:

- air velocity and gap measurement
- air velocity, gap measurement and differential pressure measurements on selected rooms

The chapter outlines the equipment used and the test protocols.

EQUIPMENT

The equipment used in the experimental work was:

- air velocity meter
- differential pressure system
- venier calipers to measure gaps accurately

Figure 9 shows the air velocity meter. The REED instruments air velocity and temperature meter, logger SD-4214, uses a hot wire anemometer to measure wind speed. A white dot on the problem provides the notice as to the upwind side of the device.

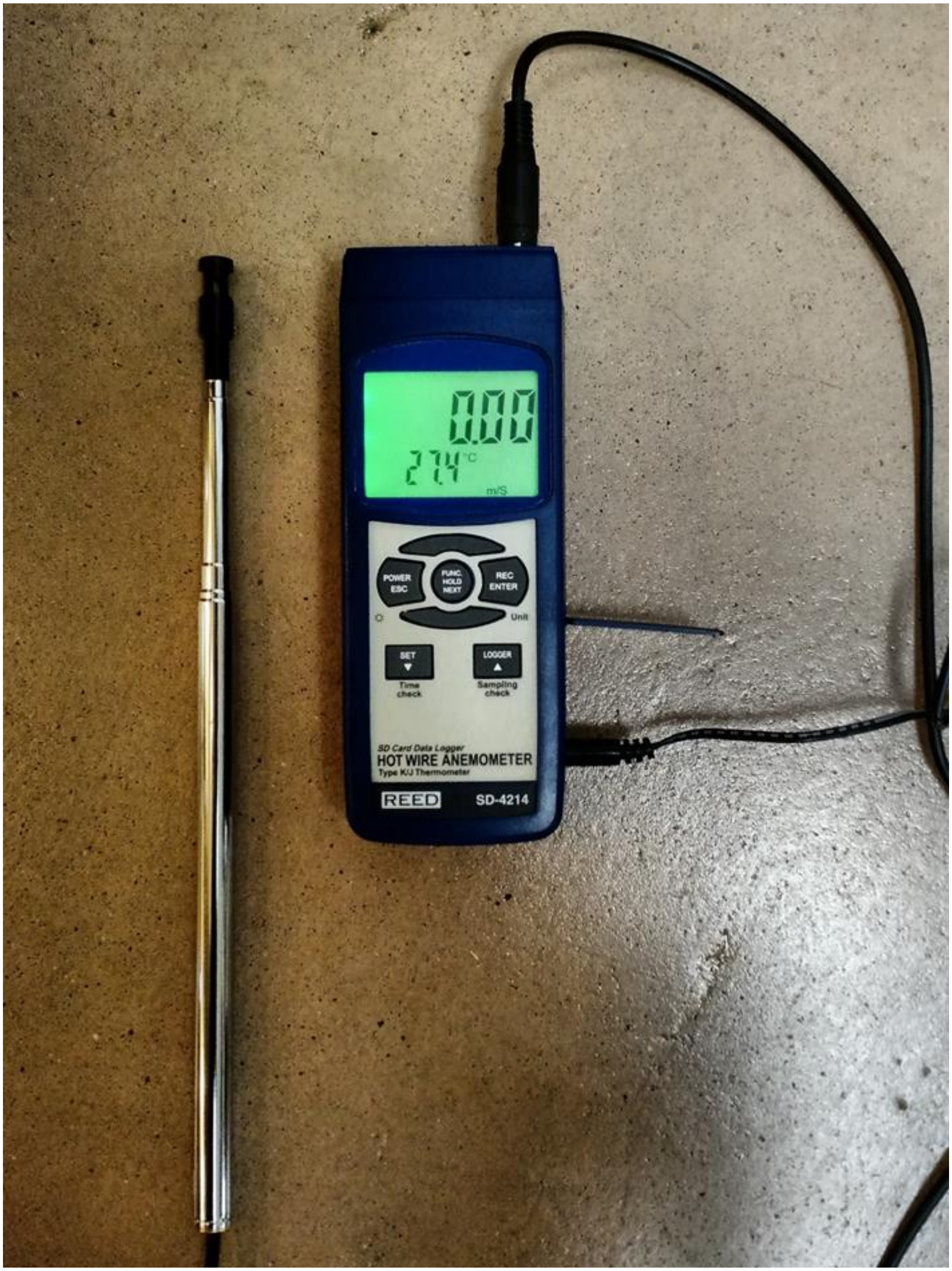

Figure 9. Thermo-Anemometer data logger SD-4214

Figure 10 shows the features and characteristics of the device from the manufacturer's fact sheets.

FEATURES

- Measures air velocity as well as temperature with a type J/type K thermocouple thermometer
- Hot wire probe for precise low air velocity measurements
- Thermistor temperature sensor for a fast response time
- Air velocity is measured in m/s, fpm, km/h, mph or knots
- Temperature is measured in °C or °F
- Automatic temperature compensation (0 to 50°C/32 to 122°F)
- Easy to read LCD with backlight
- Data hold and Max/Min record
- Real time data logger with integral 4GB SD memory card (OPTIONAL)
- Just plug the SD card into the computer and it downloads directly to EXCEL
- RS-232 and USB computer interface
- Auto or manual power off

SPECIFICATIONS

Air Velocity Range: 0.2 to 25.0 m/s; 0.7 to 72.0 km/h; 0.5 to 44.7 mph; 40 to 3940 fpm; 0.4 to 38.8 knots
Resolution: 0.1 m/s; 0.1 km/h; 0.1 mph; 1 fpm; 0.1 knot
Accuracy: ±(2% rdg + 0.2 m/s; 0.8 km/h; 0.4 mph, 20 fpm; 0.4 knot)
Type K Temp. Range: -100.0 to 1300.0°C (-148.0 to 2372°F)
Resolution: 0.1°C/°F
Accuracy: ±(0.4% +0.5°C/+1°F)
Type J Temp. Range: -100.0 to 1200.0°C (-148.0 to 2192°F)
Resolution: 0.1°C/°F
Accuracy: ±(0.4% +0.5°C/+1°F)
Auto Sampling Time: 1, 2, 5, 10, 30, 60, 120, 300, 600, 1800, 3600 seconds
Power Supply: 6 x 1.5V UM3/AA batteries
Dimensions: 203 x 76 x 38mm; Telescopic Probe: ø 12mm dia., 280mm to 940mm long
Weight: 515g

Figure 10. Thermo-Anemometer data logger SD-4214 features and specifications from REED (2014)

This instrument was used to measure air velocity in meter/second unit. The velocity was measured on all four possible gaps on a door and for the exceptional cases where velocity was measured to be too high thru the gap, there was further investigation conducted with the use of pressure meter to look at the room's pressure response to the high velocities.

Figure 11 shows Setra Model 267MR Multi-Range Low Differential Pressure Transducer

Figure 11. Setra Model 267MR Pressure Manometer from Setra (2016)

Setra 267 MR is capable of measuring differential pressure from 0.1 inches of a water column. to 10 inches of a water column W.C. It is able to achieve this with an output measurable range of 4mA-20mA.

Figure 12 shows the product overview and the specifications from the manufacturer.

PRODUCT OVERVIEW

The Model 267MR is Setra's most highly configurable multirange low differential pressure transducer. It offers multi-range capability with 6 field selectable ranges and 2 field selectable outputs that are easily configured by flipping a Dip Switch. The 267MR is housed in a NEMA 4 rated enclosure with an optional static pressure probe reducing installation and material costs. It delivers ±0.25%, ±0.4% and ±1% FS accuracy options with pressure ranges from 0.1" W.C. up to 100" W.C.

All Inclusive Field Selectable Design - The 267MR is the ideal product for any contractor to stock in their truck; combining the flexibility of a multi-range with the performance of a single-range transducer to ensure the installer has the right solution for any job.

Robust Enclosure for Difficult Applications - The 267MR is housed in a NEMA 4 rated housing and is built to withstand harsh environments. The 267MR is available in both wall and duct mount providing the installer with flexible mounting options. The wall mount allows the sensor to be installed anywhere, whereas the duct probe configuration is designed to maximize space efficiecny in difficult applications.

The Setra Sensor - The core technology of the 267MR is the all stainless steel capacitive sensing element. Setra designs and manufactures all of their sensing elements resulting in full control over the process and quality of every single sensor. The welded dead-ended capacitive sensors requires minimal amplification and delivers excellent accuracy and longterm stability. Setra's technology has been used in over 8 million installations and has the highest field acceptance rate in the industry.

PRODUCT SPECIFICATIONS

- 6 Field Selectable Ranges
- 2 Field Selectable Outputs
- NEMA 4 Rated Housing
- PG-9, PG-13 or Conduit Electrical Termination
- Integral Static Pressure Probe
- 24 VAC or 24 VDC Excitation
- Meets CE Conformance Standards

Figure 12. Product overview and specifications from Setra (2016)

Figure 13 shows Versa Logger, which is used to record the data output from the differential pressure gauge. The figure shows:

- power supply with input 120 volt power cable in orange
- data logger, with the green inputs from the SETRA device
- a black grounding system

The entire system is mounted in an electrical box for safety.

Figure 13. VersaLog DCVC-HR with power source

Figure 14 shows one side of the product specification for the datalogger.

Inputs	
Channels	CH1 ~ CH4 (voltage): programmable range for each: 0 ~ 20 V, 0 ~ 2 V, CH5 ~ CH7 (current) programmable range for each: 0 ~ 20 mA
Accuracy	Thermistor channel: reference temperature 0.36°F
	Voltage channels: +/- 0.05% FSR @ 25°C for 20V channels, +/- 0.1% FSR @ 25°C for 2V channels
	Current channels: +/- 0.15% FSR @ 25°C
Load Resistor	For current channel: 12 Ohms
Protection	Voltage channel: +/- 40 VDC, Current channel: +/-100 mA

Alarms	
Channel Alarms	Two editable alarm thresholds per channel
Alarm Outputs	ALARM1 & A2/EXT terminal strips can be configured as alarm outputs
	Alarm-On: MOSFET (N-Channel) switch on Alarm-Off: MOSFET (N-Channel) switch off
	Max Power: 200mA @ 24VDC
	Can report alarm status to host PC via USB, Modem or Ethernet Device Server with SiteView software[2]
Alarm-On Delay	Programmable 0 - 10 minutes delay with 1-minute increments
Alarm Indicator	On-board LED lights in red when in alarm condition

On-Board Memory	
Capacity	4MB ~ 2 million measurements
Data Retention	Over 20 years

Sampling & Logging	
Sampling Interval	20 milliseconds[1] to 12 hours user selectable
Logging Mode	Stop recording or FIFO when memory is full
Logging Activation	Programmable instant, start delay or field push-button activation

Figure 14. Product specifications and features part I from CASData-loggers (2015)

Figure 15 shows the second page.

Communications	
Interface	USB (USB cable included), AUX (RJ11) for direct TTL level communications
	Can be connected to Ethernet for remote access with DeviceServer Kit[2]
Baud Rate	Auto-detect baud rate from 2400 to 115200 bps on both USB and AUX ports

Battery	
Power	Built-in 3.6V Lithium Battery
Life Cycle	10 years based on 1 minute sampling interval

Software	
SiteView[2]	Configuration, downloading, plotting, real-time view, custom calibration and custom equation
Software Requirements	Computer with 1.0 GHz or faster processor, 256 MB Memory or higher & 1.0 GB of available hard-drive space or higher
	Windows XP with SP2 or later, Vista, Windows 7, 8
	At least one USB port or one COM port

Other	
LED Indicator	Normal Sampling: green when sampling Alarm: red when sampling Low Battery: amber when sampling
Excitation Control	A2/EXT terminal strip can be configured as excitation control output for powering connected devices
	Warm-up delay Interval settings: 10 to 240 seconds with 10-second increments
Operating Environment	-40 ~ +70°C (-40°F ~ 158°F), 0~95%RH non-condensing
Clock Accuracy	+/- 1 minute per month
Approvals	CE, FCC

[1]: Maximum enabled channel: 1 for 20ms interval, 2 for 30ms, 8 for 40ms or bigger interval.

[2]: Sold separately.

Figure 15. Product specifications and features part II from CASData-loggers (2015)

Figure 16 shows the complete assembly with the white pressure tubes.

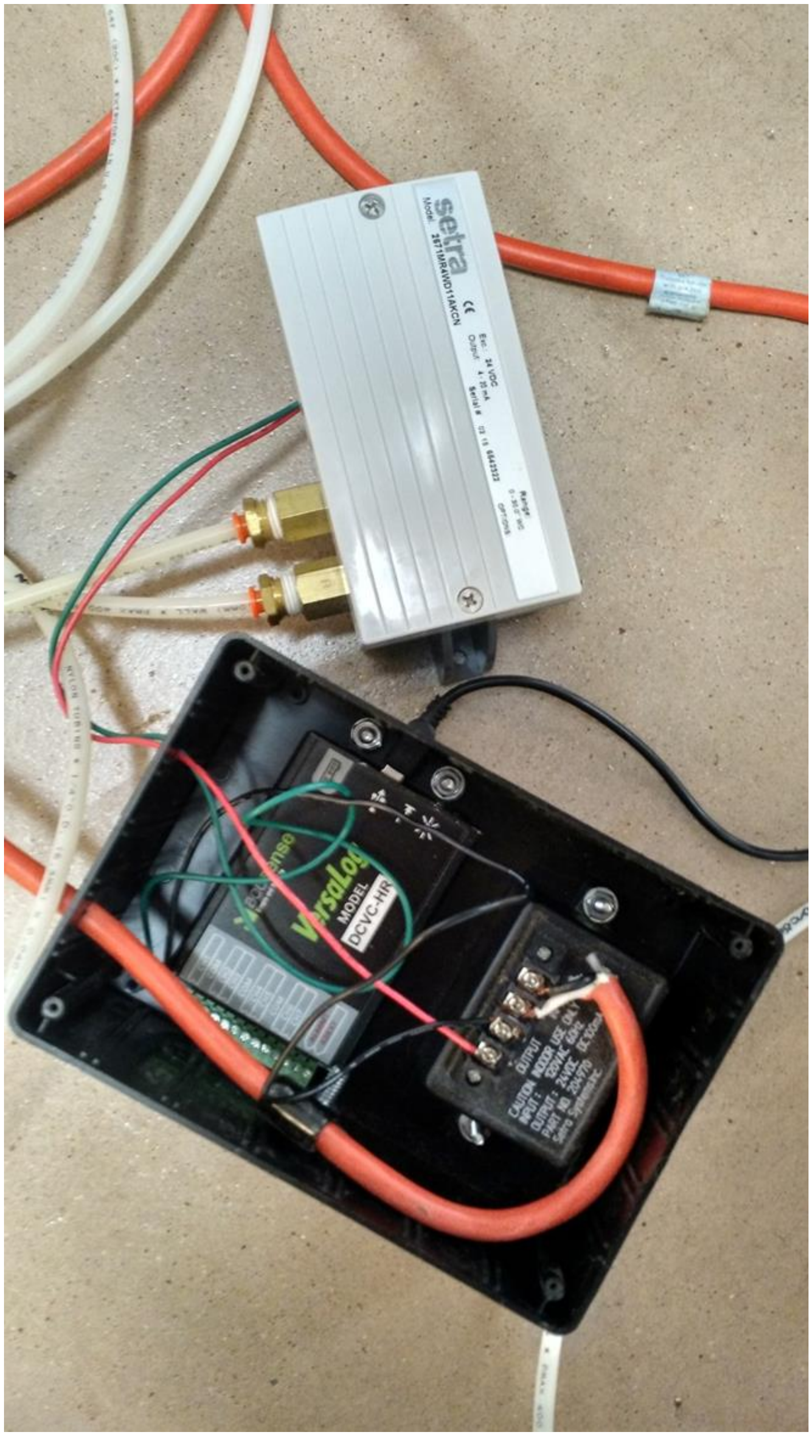

Figure 16. VersaLog-Setra assembly

Figure 17 shows the vernier calipers. The instrument shown is capable of measuring in inches and millimeters with an accuracy of ± 0.001" or 0.02mm respectively. This instrument was used to measure door gaps.

Figure 17. Pittsburgh 150 mm digital caliper

Figure 18 shows the eight meter tape measure.

Figure 18. Tape measure 8 metres

TEST BUILDING

The test building used is Langford Architectural Complex Building A. Figure 19 shows the front view of the building in the centre of the photograph taken from Google Earth.

The building has an open plan and an interesting air handling system. Figure 20 shows the Langford Level 1 or ground level, with the room 107 A in the bottom left hand corner of the floor.

Figure 19. Langford Architectural Complex Building A from Google Earth, 2016

Figure 20. Langford level 1

Figure 21 shows the second level on Langford. The open nature of the building is evident in the plan.

Figure 21. Langford level 2

Figure 22 shows the fourth level of the building.

Floors 1, 2 and 4 of Langford A building at Texas A&M University were selected to conduct the study.

Figure 22. Langford level 4

SAMPLE DOOR

A standard door is used at Langford Building A. The door in Figure 23 shows the standard door with the gap locations shown as follows:

- H is the door height
- W is the door width
- G1 is the gap along the top of the door
- G2 is the gap along the right hand side of the door looking from the corridor
- G3 is the gap along the bottom of the door
- G4 is the gap along the left hand side of the door looking from the corridor

Figure 24 shows the methods of measurement used to determine the lengths and gaps.

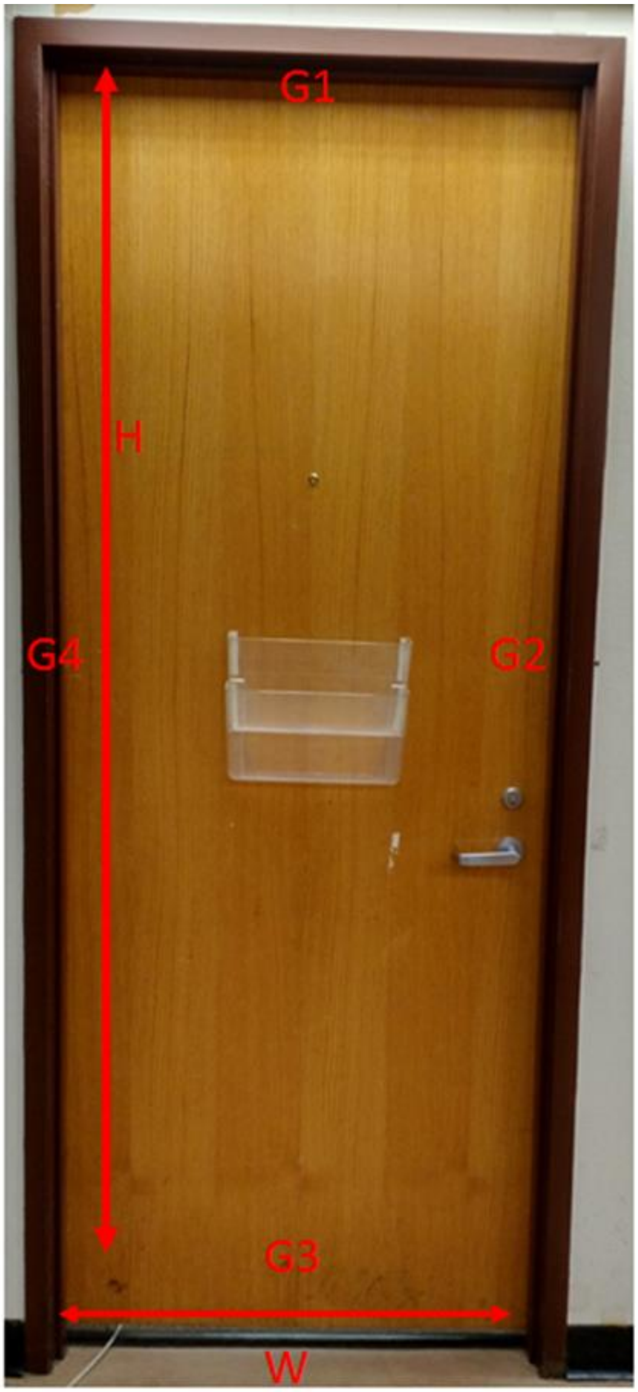

Figure 23. Standard door at Langford A

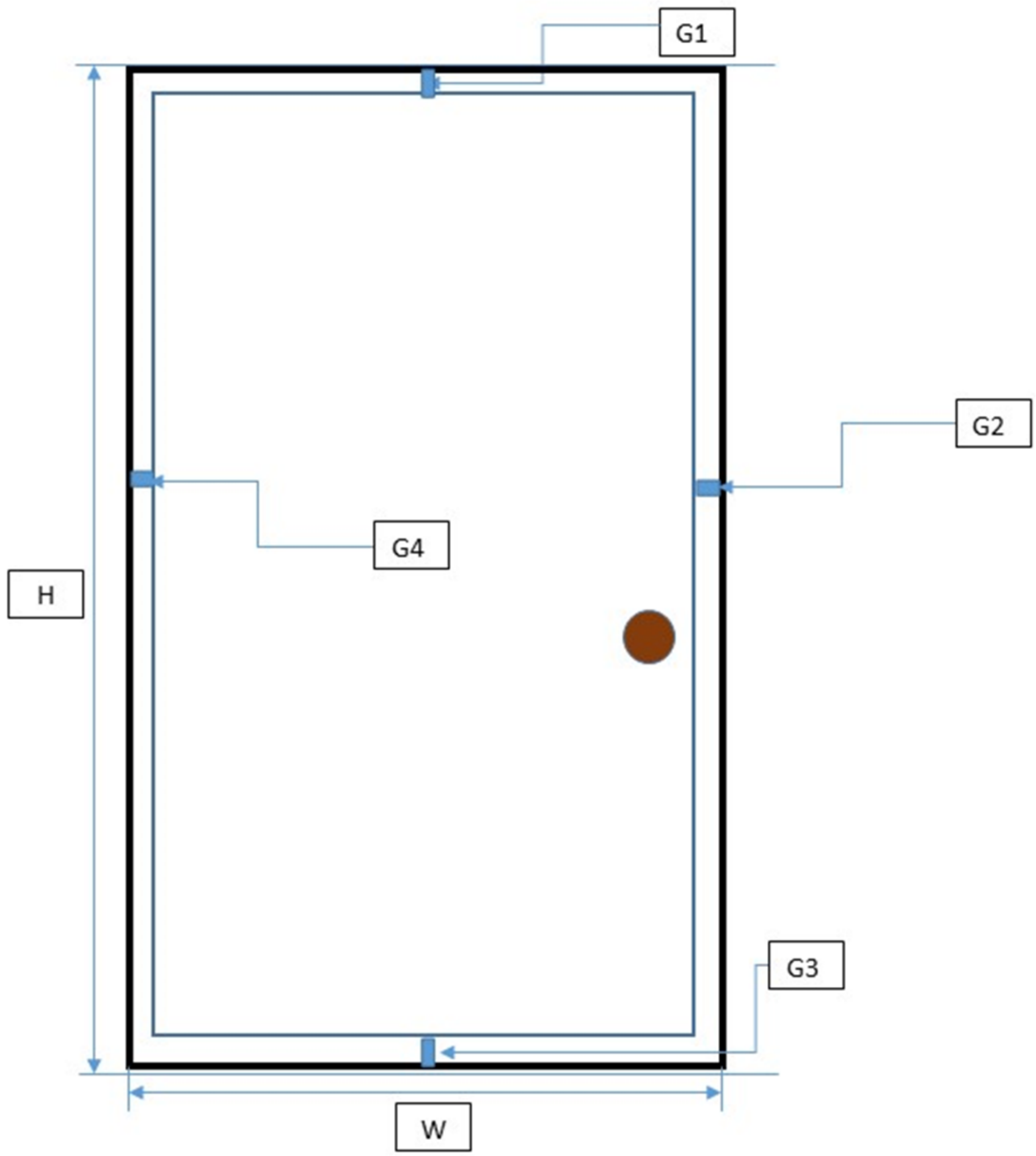

Figure 24. Standard door – methods of measurement

SOFTWARE

The anemometer has an internal data logger, which can be then moved to an SD card.

The differential pressure meter was recorded using SiteView software as shown in Figure 25.

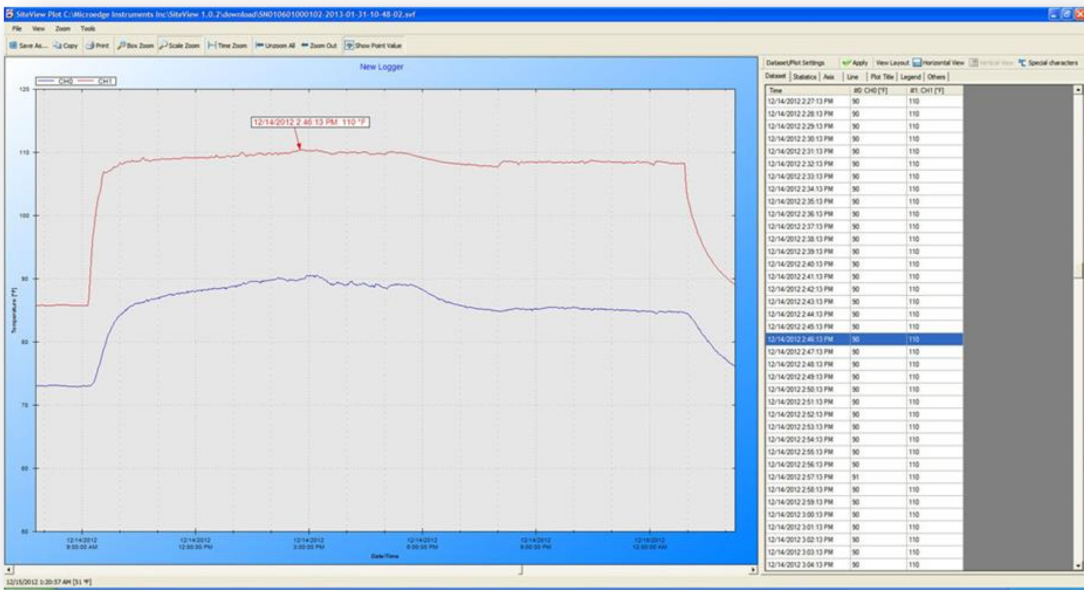

Figure 25. Screenshot of SiteView from CASData-logger (2015)

Figure 26 shows the complete work station. A Dell XPS computer is used as the CPU unit for all work.

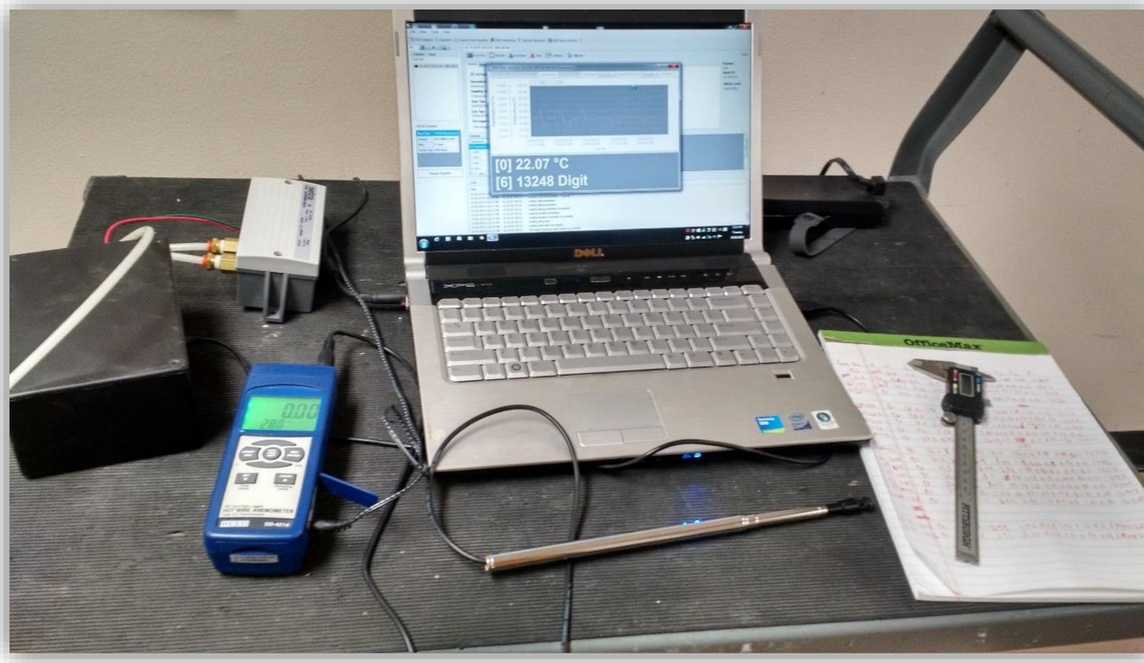

Figure 26. Workstation

TEST METHODS

The test methods were

- the doors were selected at random in Landford A on level 1, 2 and 4 to conduct the study
- W is the door width, was measured for each door with an accuracy of ± 1 mm
- H is the door width, was measured for each door with an accuracy of ± 1 mm
- the doors were selected at random in Landford A on level 1, 2 and 4 to conduct the study
- the velocity for the doors was measured at the centre of the side, for a minumium of 2 minutes per door

- The measurements were uniformly measured in meter/second (m/s) unit. To understand the magnitude of observations better, 1 m/s = 2.23694 miles/hour or 3.6 kilometres/hour.

  Two rooms had interesting results and pressure differentials were measured with the door closed between the inside and outside of the door

CHAPTER IV

RESULTS

INTRODUCTION

This chapter summarizes the results of the experiments. The chapter presents:

- Room Selection
- Gap and velocity measurement - summary
- Gap and velocity measurement: gap one-four
- Average and pressure measurements

ROOM SELECTION

The experimental work was completed on the February 23, 2016. The temperature at the time was 65° F. The rooms selected for the study were:

- Room 103 – Level 1 which is a faculty office
- Room 107 – Level 1 which is a studio
- Room 127 – Level 1 which is a faculty office
- Room 122J – Level 1 which is a faculty office
- Room 206 – Level 2 which is a faculty office
- Room 205 – Level 2 which is a faculty office
- Room 217 – Level 2 which is a conference room
- Room 216 – Level 2 which is a faculty office

- Room 413 – Level 4 which is a faculty office
- Room 414 – Level 4 which is a faculty office
- Room 428 – Level 4 which is a faculty office
- Room 429 – Level 4 which is a faculty office
- Room 430 – Level 4 which is a faculty office
- Room 440 – Level 4 which is a faculty office
- Room 441 – Level 4 which is a faculty office
- Room 437 – Level 4 which is a faculty office
- Room 444 – Level 4 which is a faculty office
- Room 443 – Level 4 which is a faculty office

GAP AND VELOCITY MEASUREMENT - SUMMARY

Table 4 summarizes the door measurements, the gap and the velocity measurements for rooms numbered 103 to 414. Table 5 summarizes the gap and velocity measurements for rooms numbered 428 to 443.

Table 4.

Gap and velocity measurement – part I

Test	Room	Dimensions (inches)		Gap Measurements (mm)				Velocity (m/s)			
No.	No.	H	W	1	2	3	4	1	2	3	4
1	103	90	34.5	1.40	1.60	18.06	1.70	1.06	0.42	1.88	0.48
2	107	90	34.5	2.20	6.42	17.62	0.30	0.21	0.35	2.10	0.15
3	127	90	34.5	2.14	1.92	19.33	1.28	0.24	0.14	1.43	0.20
4	122J	90	34.5	2.11	1.72	10.18	0.34	0.32	0.19	0.79	0.31
5	206	90	38.5	1.96	1.84	13.40	1.22	0.25	0.36	1.20	0.14
6	205	90	38.5	1.74	1.67	17.12	1.44	0.18	0.24	0.88	0.24
7	217	90	38.5	2.02	2.11	11.49	1.67	0.24	0.33	3.57	0.19
8	216	90	72	2.18	3.84	9.89	2.04	0.11	0.42	1.12	0.24
9	413	90	34.5	0.98	1.12	16.14	1.20	0.02	0.11	0.77	0.14
10	414	90	34.5	2.11	1.99	4.13	1.04	0.19	0.18	0.88	0.21

Table 5.

Gap and velocity measurement – part II

Test	Room	Dimensions (inches)		Gap Measurements (mm)				Velocity (m/s)			
No.	No.	H	W	1	2	3.	4	1	2	3	4
11	428	90	34.5	3.11	3.18	5.07	1.12	0.06	0.17	0.74	0.14
12	429	90	34.5	3.06	2.04	6.74	1.28	0.14	0.20	0.91	0.21
13	430	90	34.5	2.04	3.11	8.94	1.18	0.14	0.26	0.86	0.14
14	440	90	34.5	1.36	3.02	18.14	1.16	0.19	0.16	0.98	0.11
15	441	90	34.5	3.12	1.04	16.23	1.22	0.21	0.14	1.41	0.12
16	437	90	34.5	1.11	2.09	6.45	1.14	0.21	0.16	1.21	0.21
17	444	90	34.5	2.09	1.02	5.43	1.06	0.12	0.21	0.77	0.28
18	443	90	34.5	1.11	3.04	5.14	1.11	0.24	0.14	0.81	0.20

Figure 27 summarizes all of the gap measurements. Clearly the largest gap occurs along the bottom of the door, which is actually where one would want a narrow gap to limit dust movement.

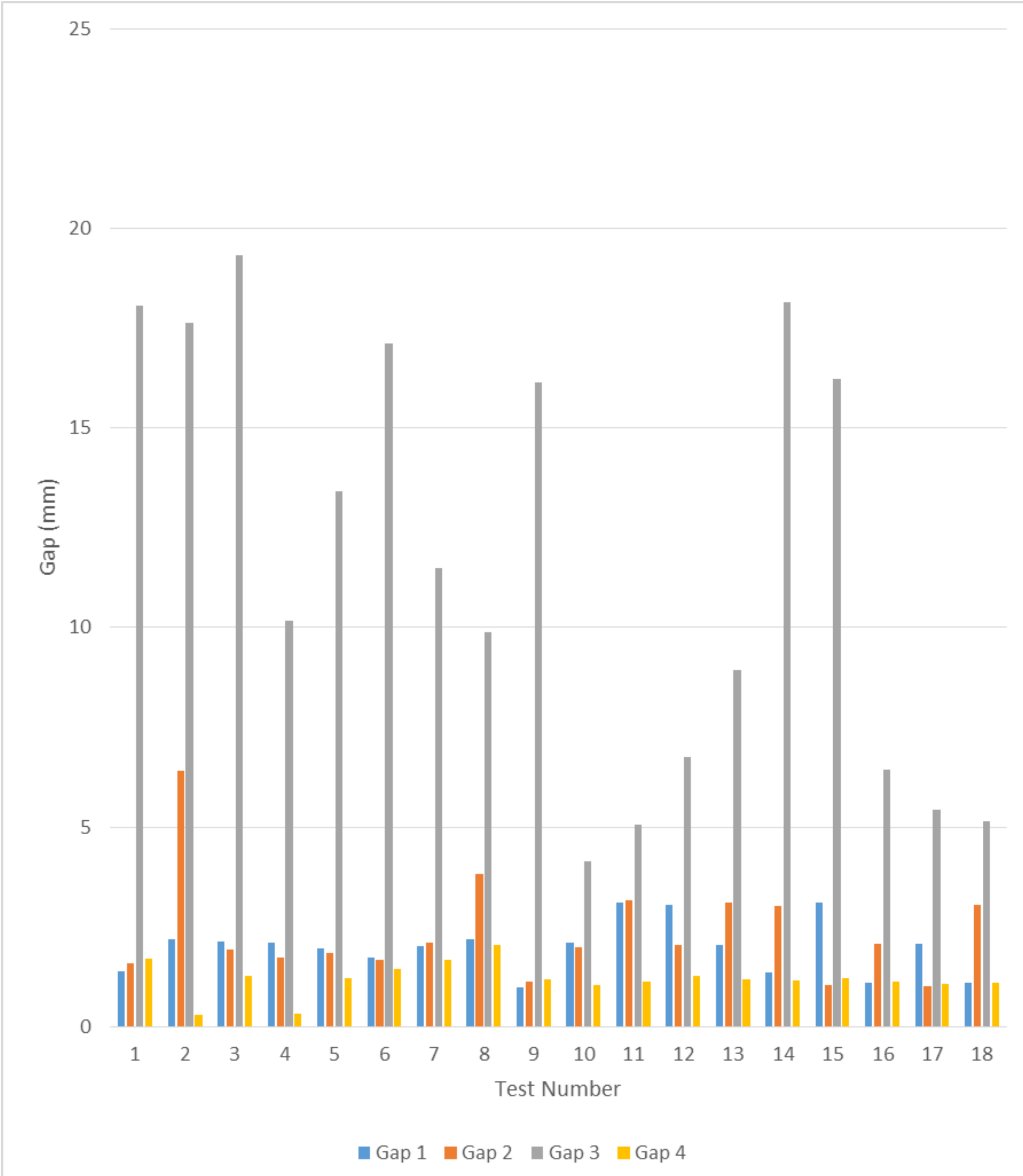

Figure 27. All gap measurements

Figure 28 shows all of the velocity measurements for the doors. The highest recorded velocity is 3.5 metres per second for door 7, which is room 217.

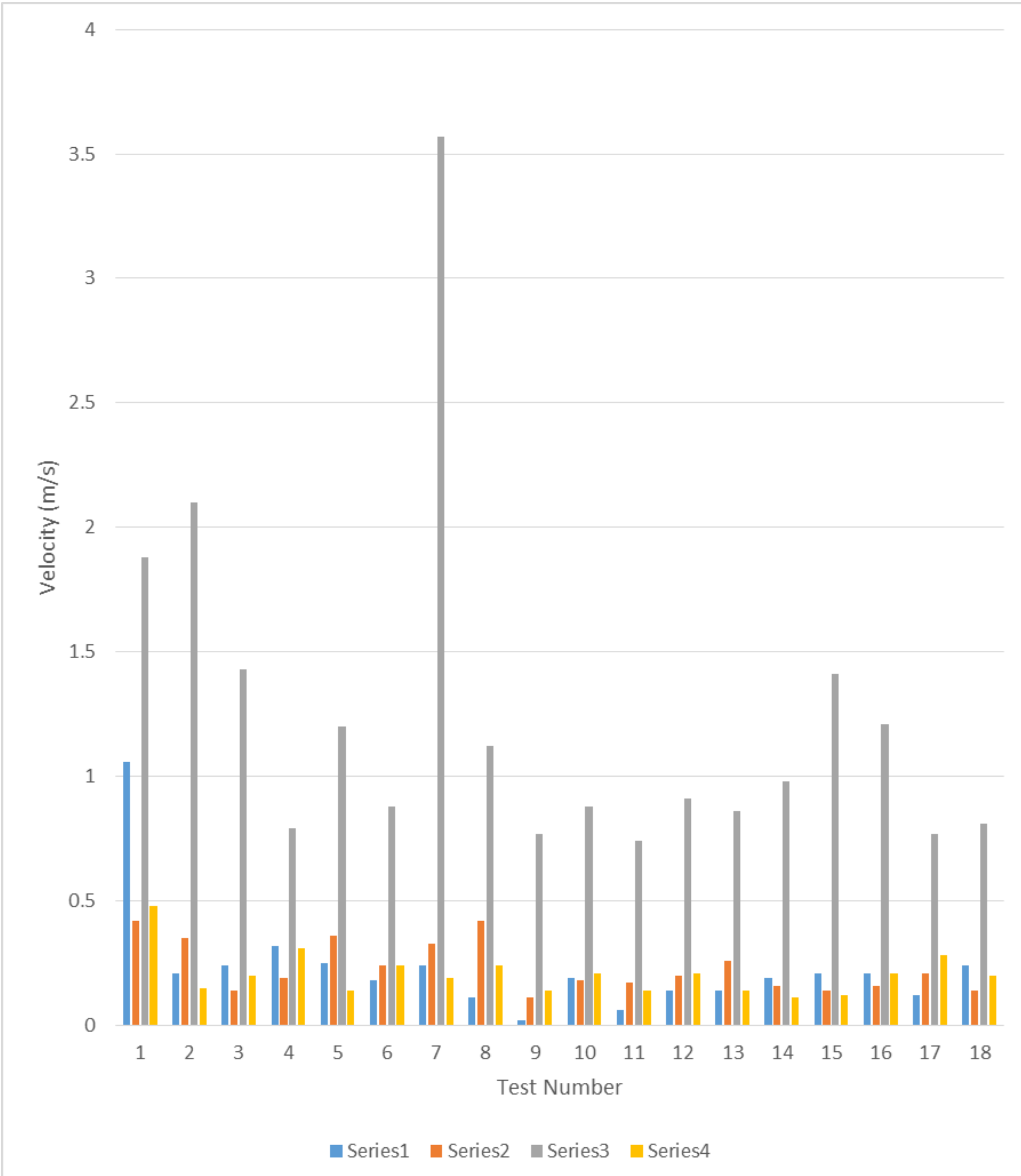

Figure 28. All velocity measurements

Table 6 shows the statistical summary for all gaps.

Table 6.

All gaps - average results

Result	Gap Dimensions millimetres				Velocity metres per second			
	1	2	3	4	1	2	3	4
Average	1.99	2.37	11.6	1.19	0.22	0.23	1.23	0.20
Standard Deviation	0.65	1.28	5.403	0.41	0.219	0.101	0.69	0.087
Skew	0.290	1.934	0.025	0.46	3.46	0.81	2.4	1.88
Kurtosis	0.32	5.02	1.676	1.7	13.6	0.6	7.0	4.83

GAP AND VELOCITY MEASUREMENT – GAP ONE

Gap One is along the top of the door.

Figure 29 shows the gap measurements for all doors for Gap One at the top of the door.

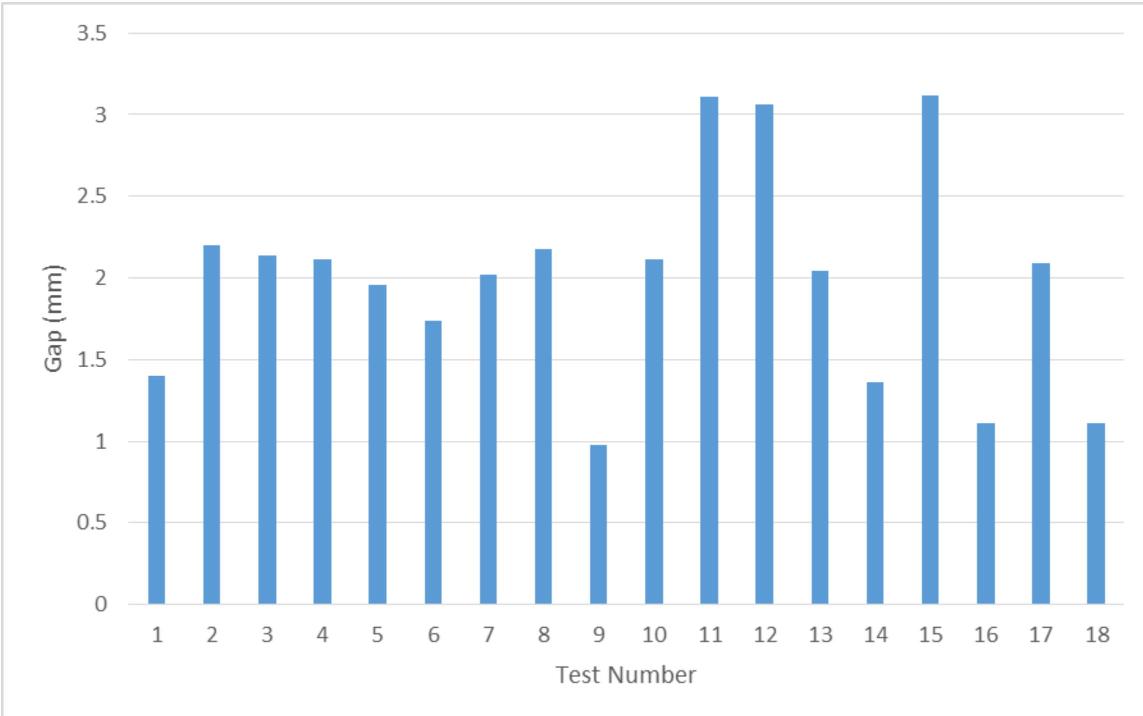

Figure 29. Gap one measurements for all doors

Figure 30 shows the gap dimension for all doors for gap one and the respective velocity measurements.

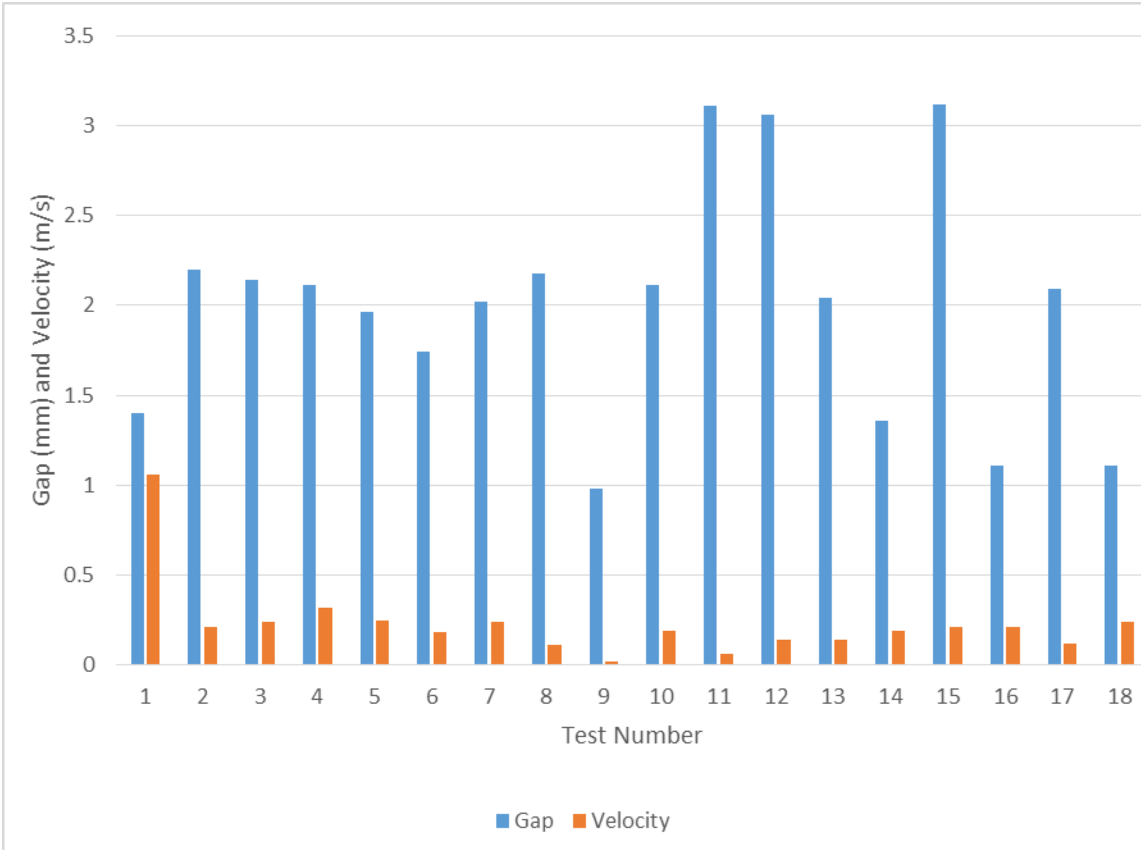

Figure 30. All doors, gap one dimension in mm and velocity in metres per second

Self-evidently a relationship does not exist between gap and velocity, which suggests significant differences in internal room pressures.

Figure 31 shows a log plot of the velocity profile for gap one.

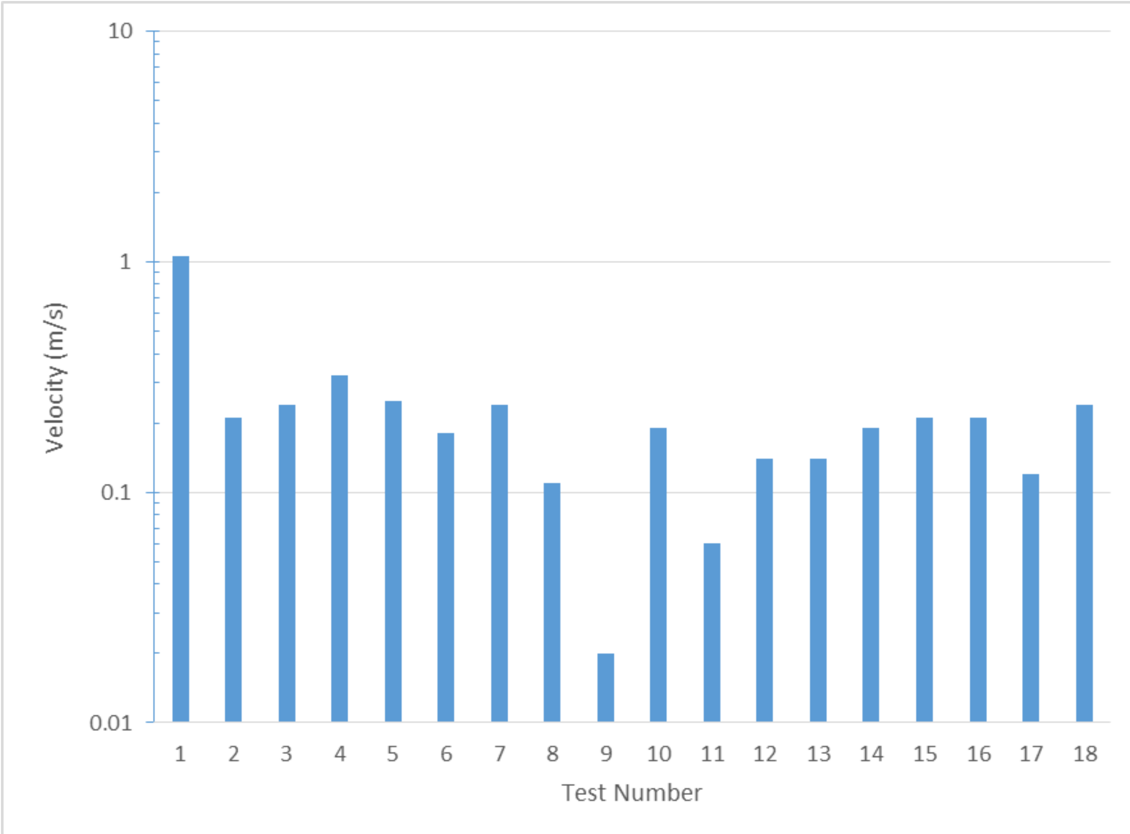

Figure 31. Velocity measurements – gap one

Table 7 summarizes the average, standard deviation, skew and kurtosis for the results.

Table 7.

Gap one - average results

Test	Gap (mm)	Velocity (m/s)
Average	1.99	0.229
Standard Deviation	0.65	0.219
Skew	0.29	3.46
Kurtosis	-0.32	13.63

The results are not normally distributed.

GAP AND VELOCITY MEASUREMENT – GAP TWO

Gap two is along the side of the door. Figure 32 shows the gap measurements for gap two for all of the doors. Room 2 and 8 have significant gaps.

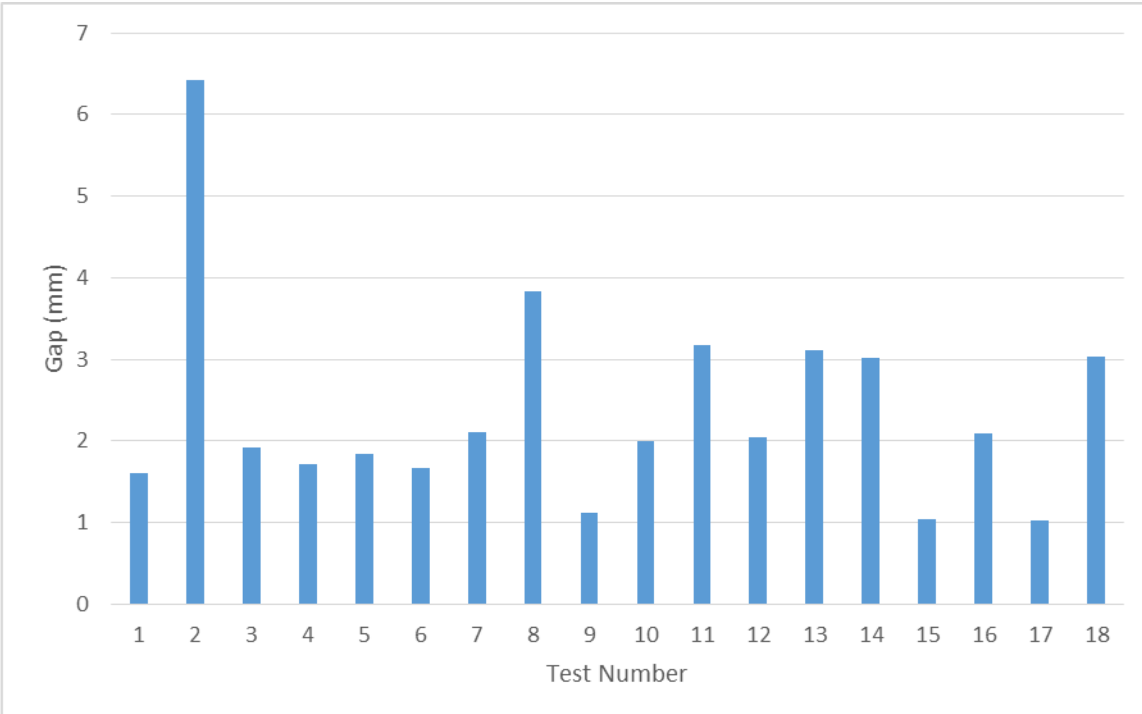

Figure 32. Gap two measurements for all doors

Figure 33 shows the gap two summary of all dimensions and velocities.

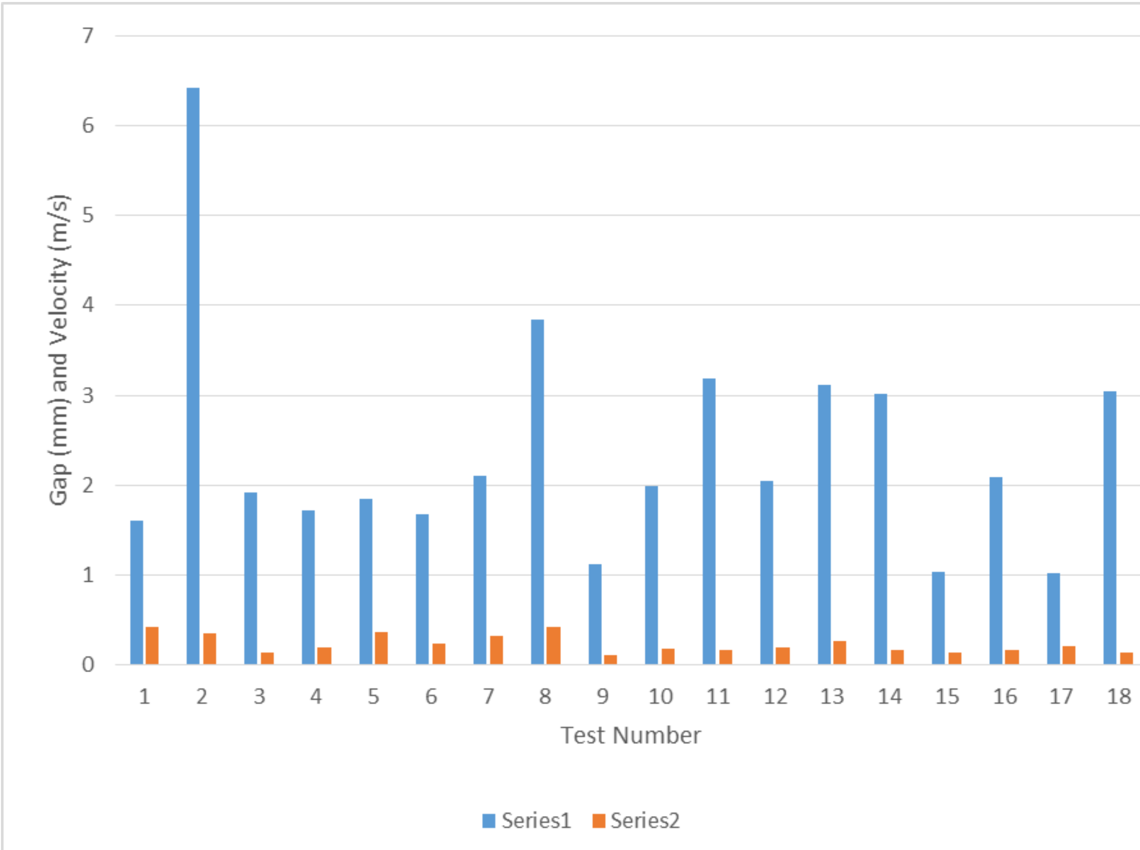

Figure 33. All doors, gap two dimension in mm and velocity in metres per second

Figure 34 shows the velocity measurements for gap two.

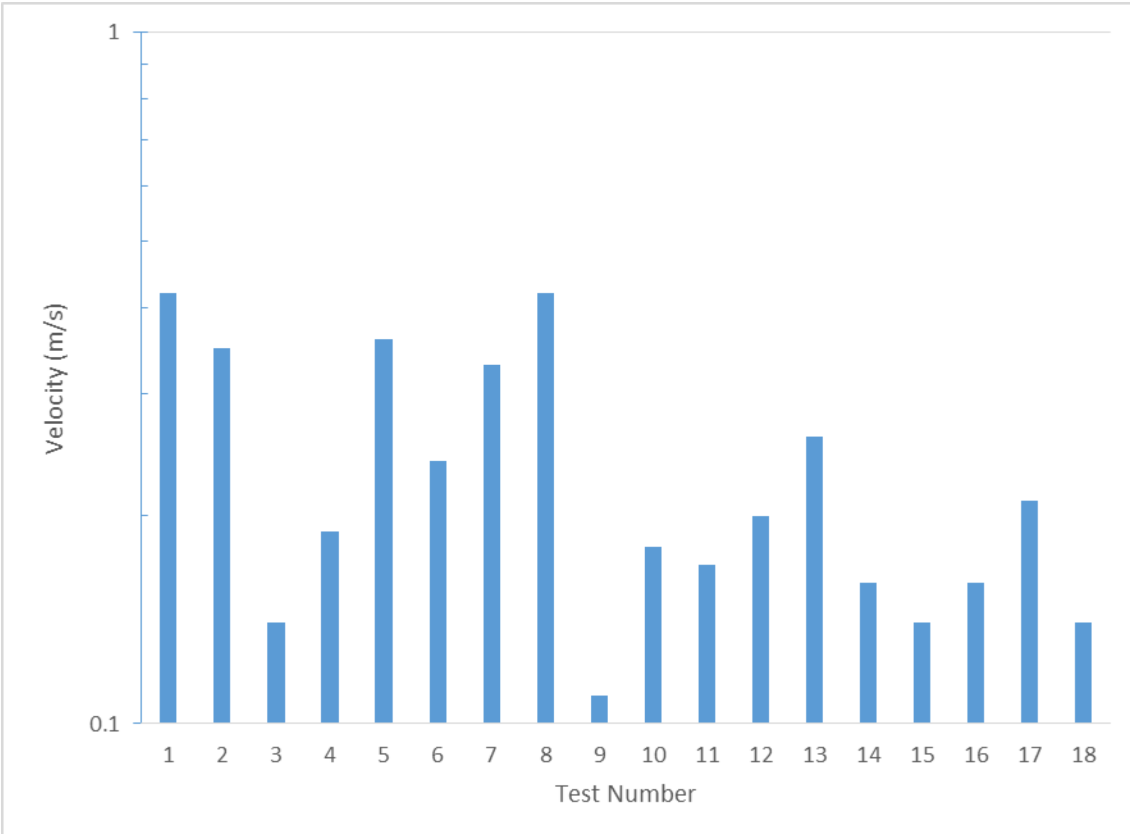

Figure 34. Velocity measurements – gap two

Table 8 shows the average results for gap two.

Table 8.

Gap two - average results

Test	Gap (mm)	Velocity (m/s)
Average	2.376111111	0.232222222
Standard Deviation	1.287492496	0.100560521
Skew	1.934614506	0.812391505
Kurtosis	5.024267444	-0.69509978

The results are not normal.

GAP AND VELOCITY MEASUREMENT – GAP THREE

Gap three is along the bottom of the door. Figure 35 shows the gap measurements for gap three for all of the doors. All rooms have significant gaps.

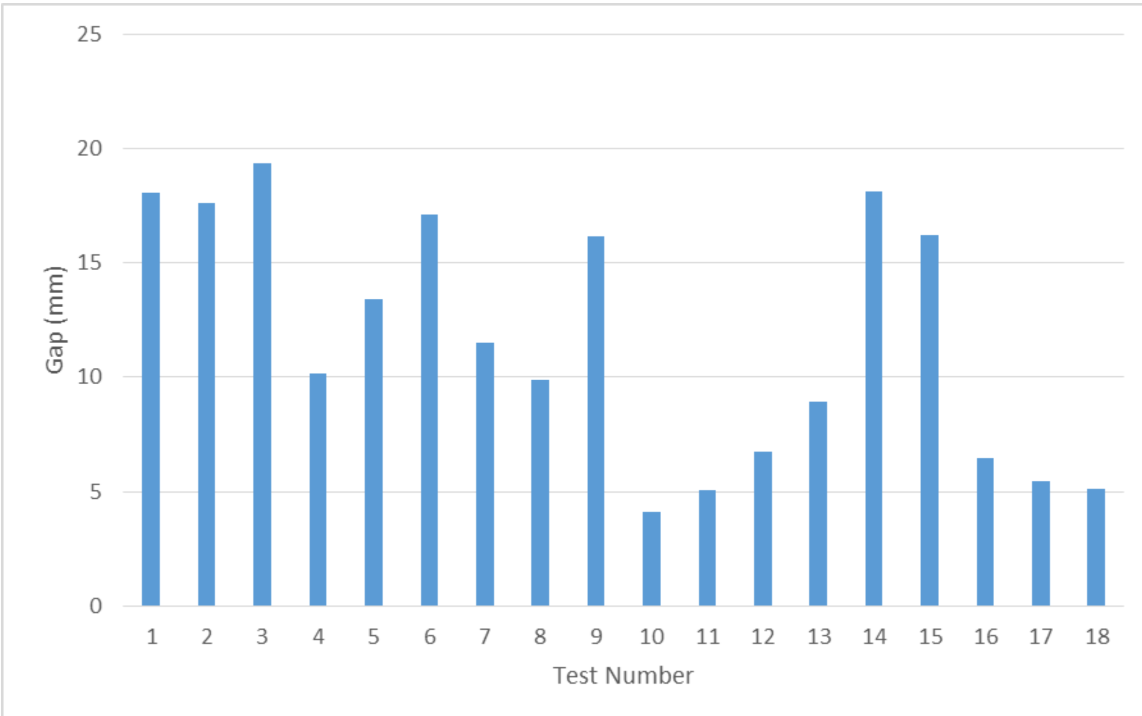

Figure 35. Gap three measurements for all doors

Figure 36 shows the gap two summary of all dimensions and velocities.

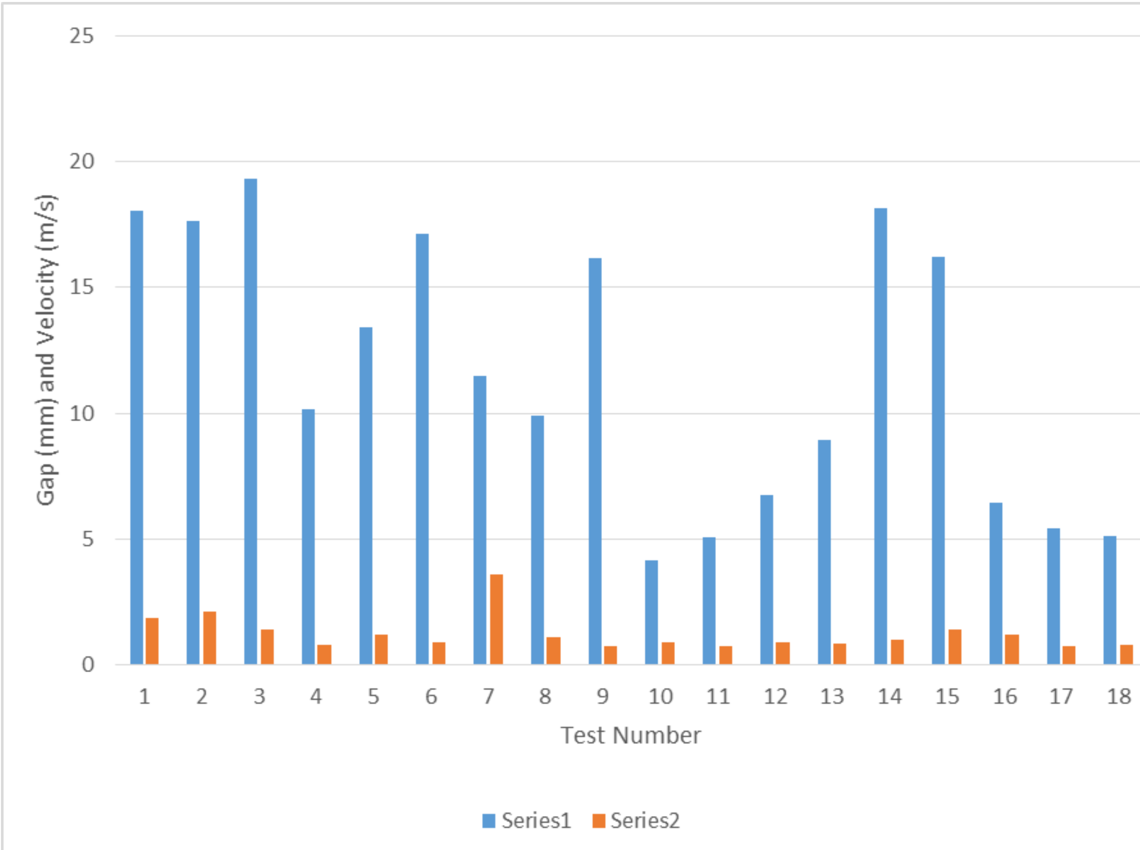

Figure 36. All doors, gap three dimension in mm and velocity in metres per second

Figure 37 shows the velocity measurements for gap three.

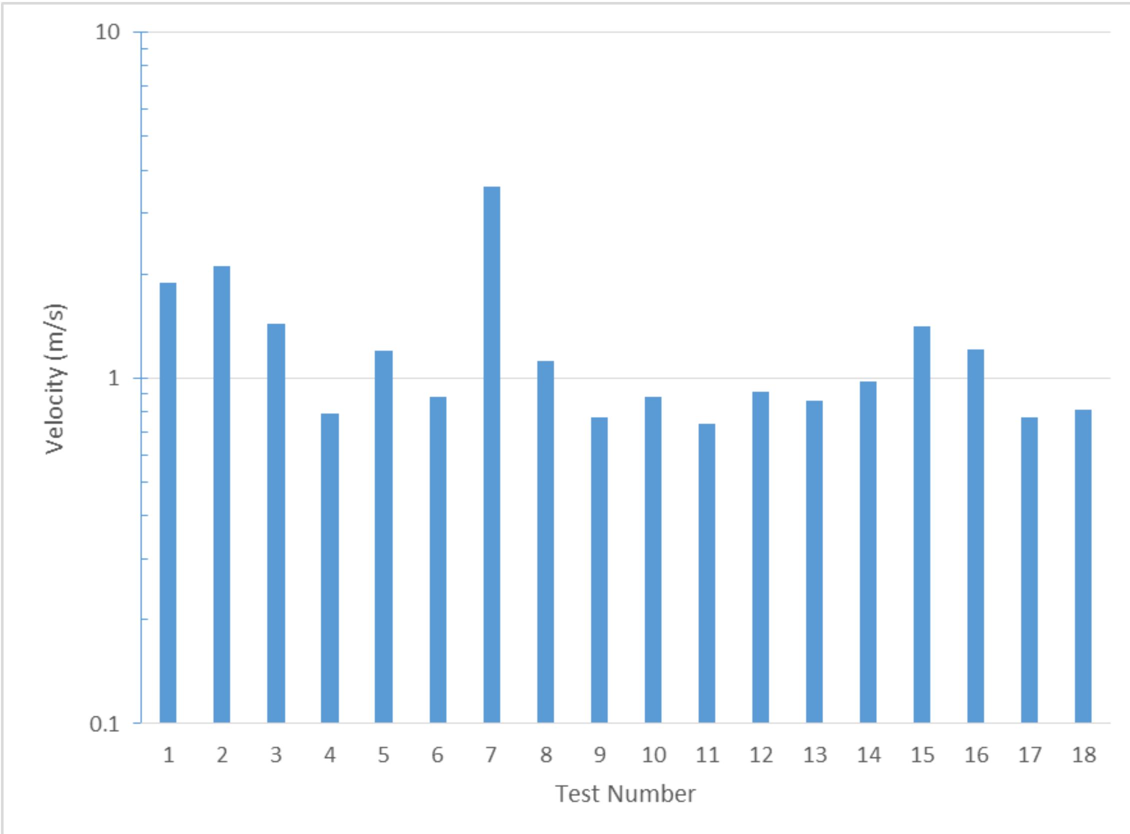

Figure 37. Velocity measurements – gap three

Table 9 shows the average results for gap three.

Table 9.

Gap three - average results

Test	Gap (mm)	Velocity (m/s)
Average	11.63888889	1.239444444
Standard Deviation	5.405012803	0.699550042
Skew	0.025341915	2.487159461
Kurtosis	-1.676590106	7.071747291

The results are not normal.

GAP AND VELOCITY MEASUREMENT – GAP FOUR

Gap four is along the side of the door. *Figure 38* shows the gap measurements for gap four for all of the doors.

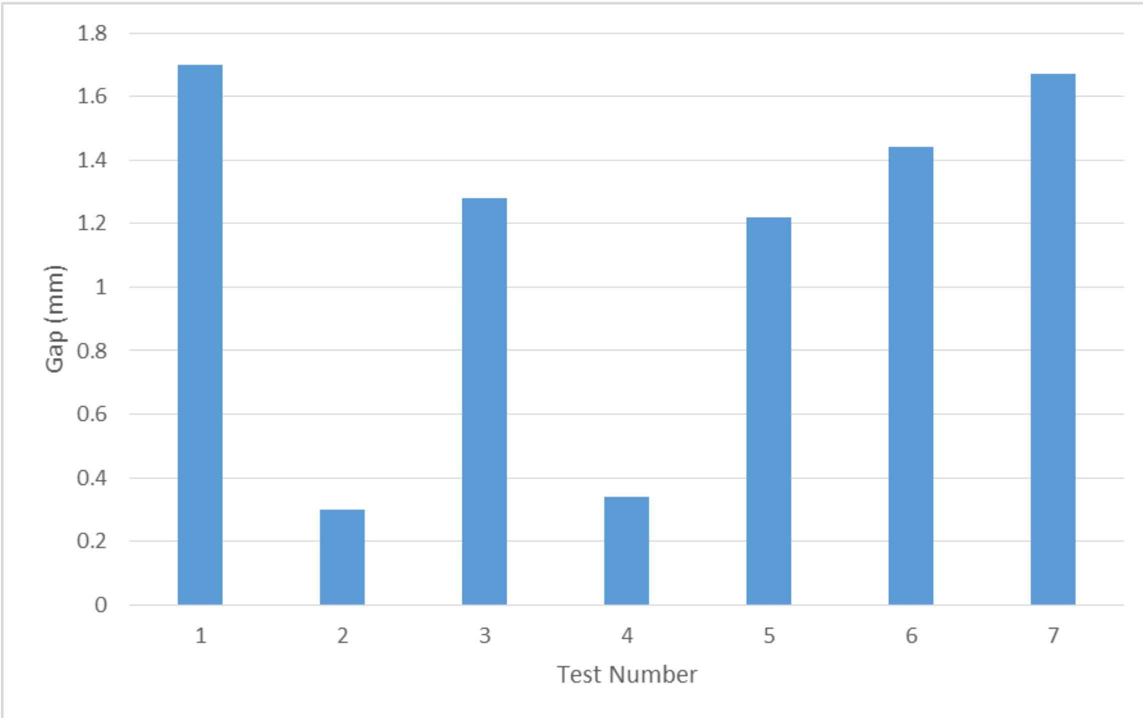

Figure 38. Gap four measurements for all doors

Figure 39 shows the gap two summary of all dimensions and velocities.

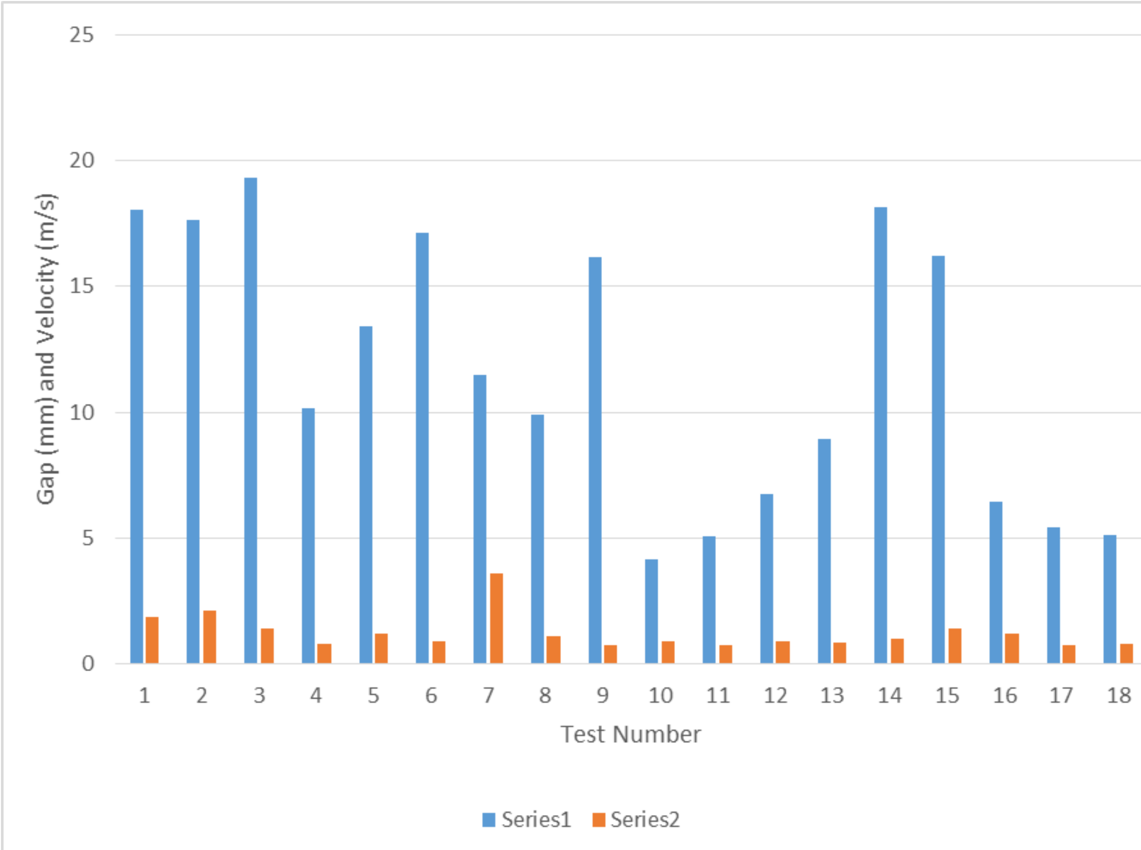

Figure 39. All doors, gap four dimension in mm and velocity in metres per second

Figure 40 show velocity measurements for gap four.

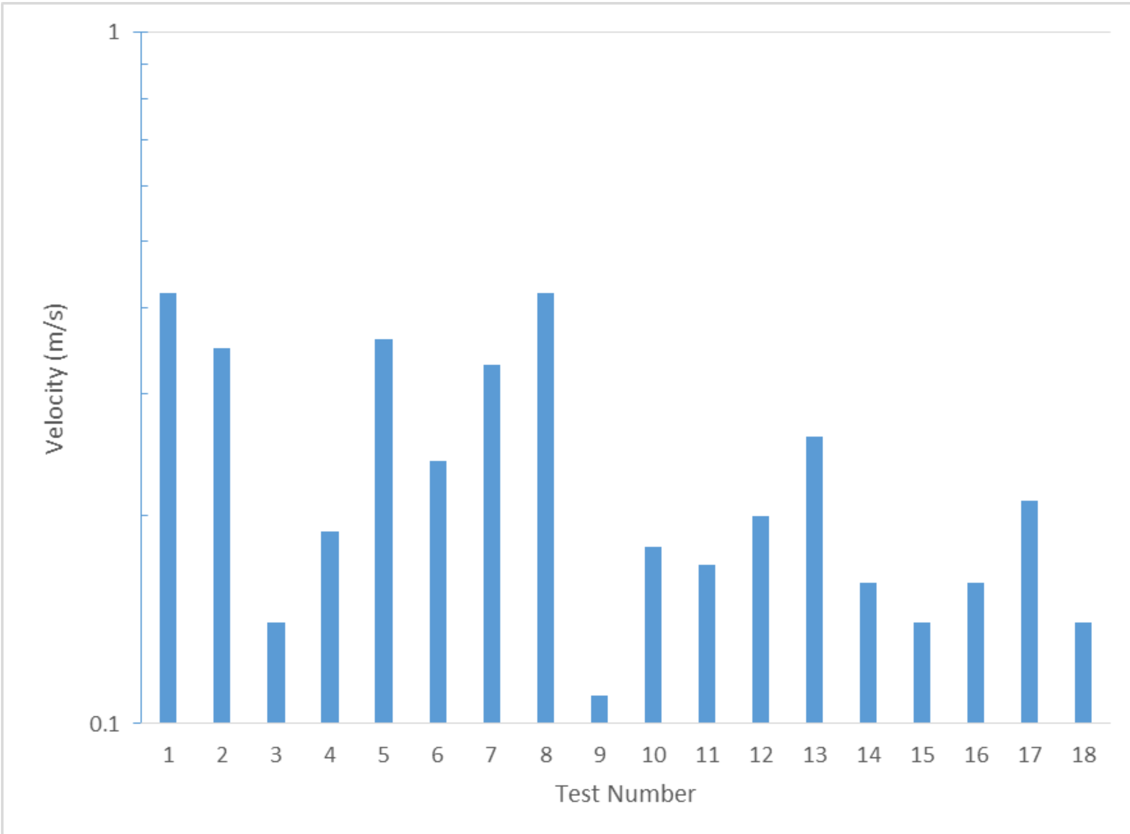

Figure 40. Velocity measurements – gap four

Table 10 shows the average results for gap four.

Table 10.

Gap four - average results

Test	Gap (mm)	Velocity (m/s)
Average	1.194444444	0.206111111
Standard Deviation	0.410311535	0.087859439
Skew	-0.468774974	1.88173766
Kurtosis	1.726902646	4.831999458

AVERAGE MEASUREMENTS

Figure 41 shows average gap all doors in each gap group.

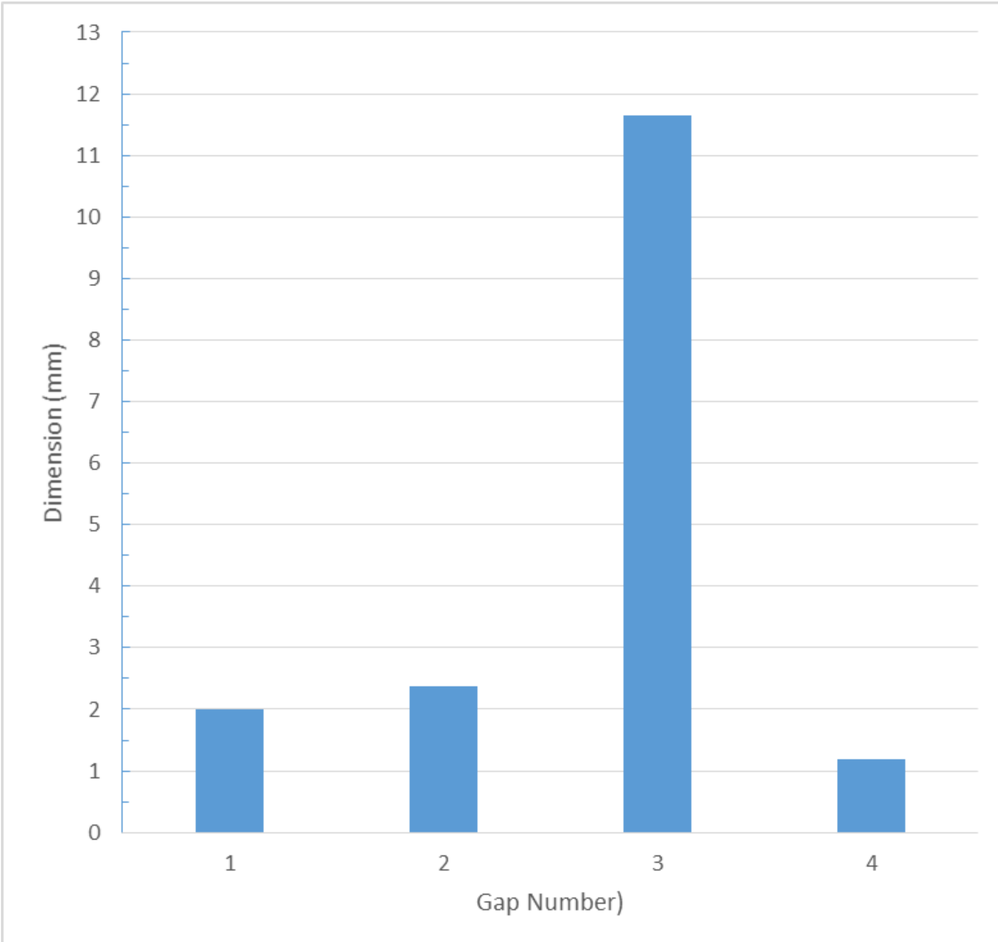

Figure 41. Average gap measurements all doors

Figure 42 shows average velocity all doors in each gap group.

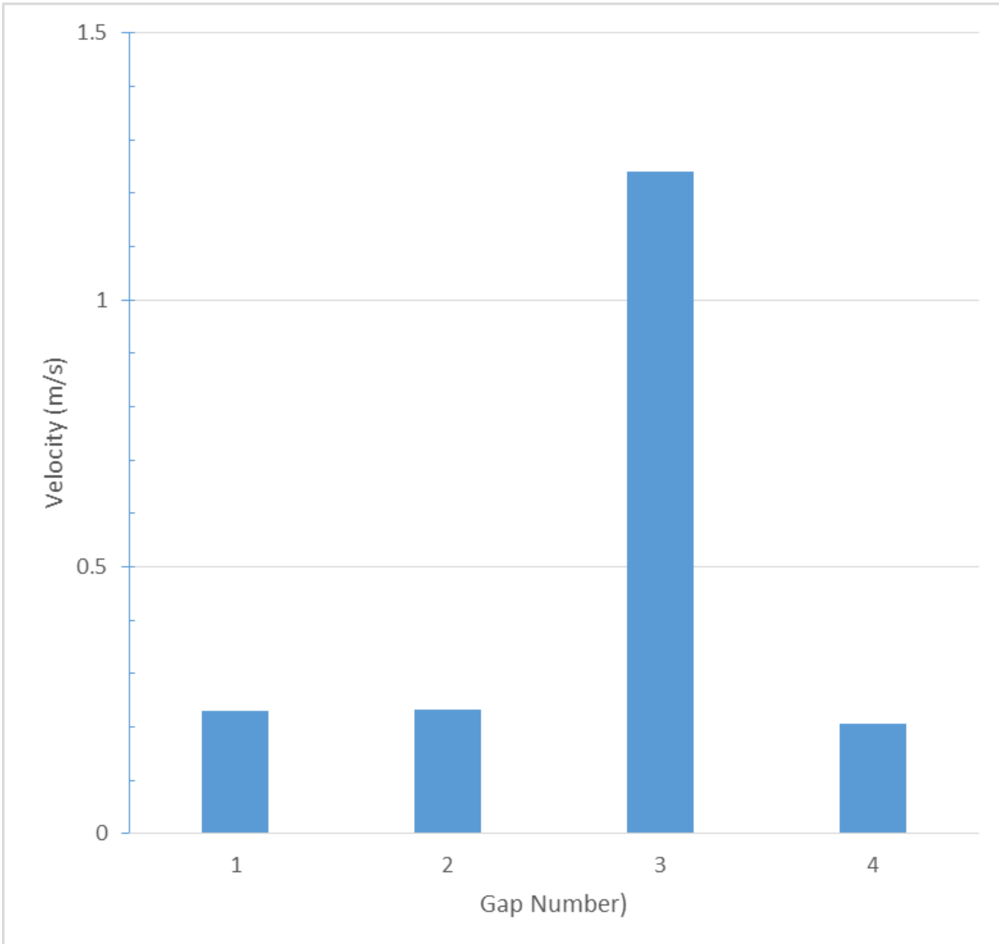

Figure 42. Average velocity measurements – all gaps

Figure 43 shows the experimental team feeling the rush of air beneath one of the doors.

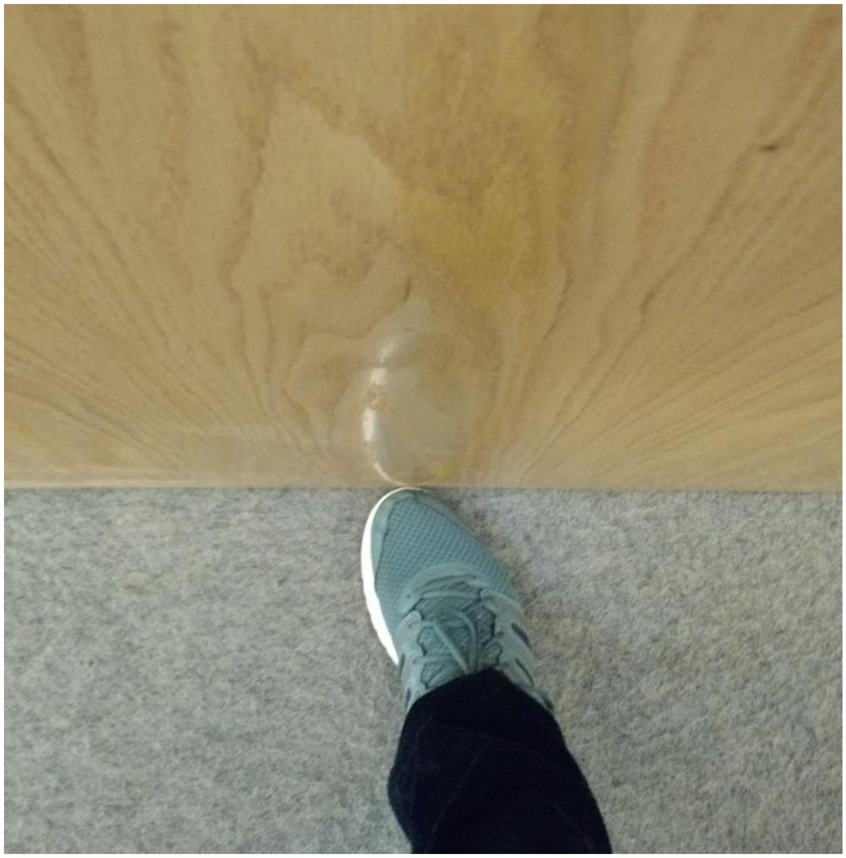

Figure 43. Feeling the air exit the room through gap G3

PRESSURE MEASUREMENTS

Room 107 was selected to conduct a detailed study of differential pressure across the door.

Differential pressures were recorded for 30 minutes. The analysis showed a cyclic pattern in the pressures, so a standard Fast Fourier transform analysis was completed in accordance with accepted theory. Table 11 shows the results of the FFT analysis.

Table 11.

Fast Fourier transform table

Index	Frequency	Cyclic Amplitude (Resolved)	Cyclic Amplitude (Real)D
1	0	9.93E-09	0
2	0.0234	5.28E-01	-0.5072
3	0.0469	5.82E-01	-0.3211
4	0.0703	2.08E-01	0.1005
5	0.0938	1.69E-01	-0.1313
6	0.1172	2.40E-01	0.0068
7	0.1406	1.28E-01	0.1122
8	0.1641	7.77E-02	-0.0766
9	0.1875	1.77E-01	-0.0357
10	0.2109	6.15E-02	0.0333
11	0.2344	1.50E-01	0.0236
12	0.2578	1.34E-01	0.1253
13	0.2812	1.20E-01	-0.1193
14	0.3047	1.78E-01	-0.0973
15	0.3281	3.55E-01	0.119
16	0.3516	4.08E-01	0.4045
17	0.375	1.85E-01	0.0986
18	0.3984	3.77E-01	0.2071
19	0.4219	5.64E-01	-0.376
20	0.4453	4.31E-01	-0.4049

Figure 44 shows the FFT plot.

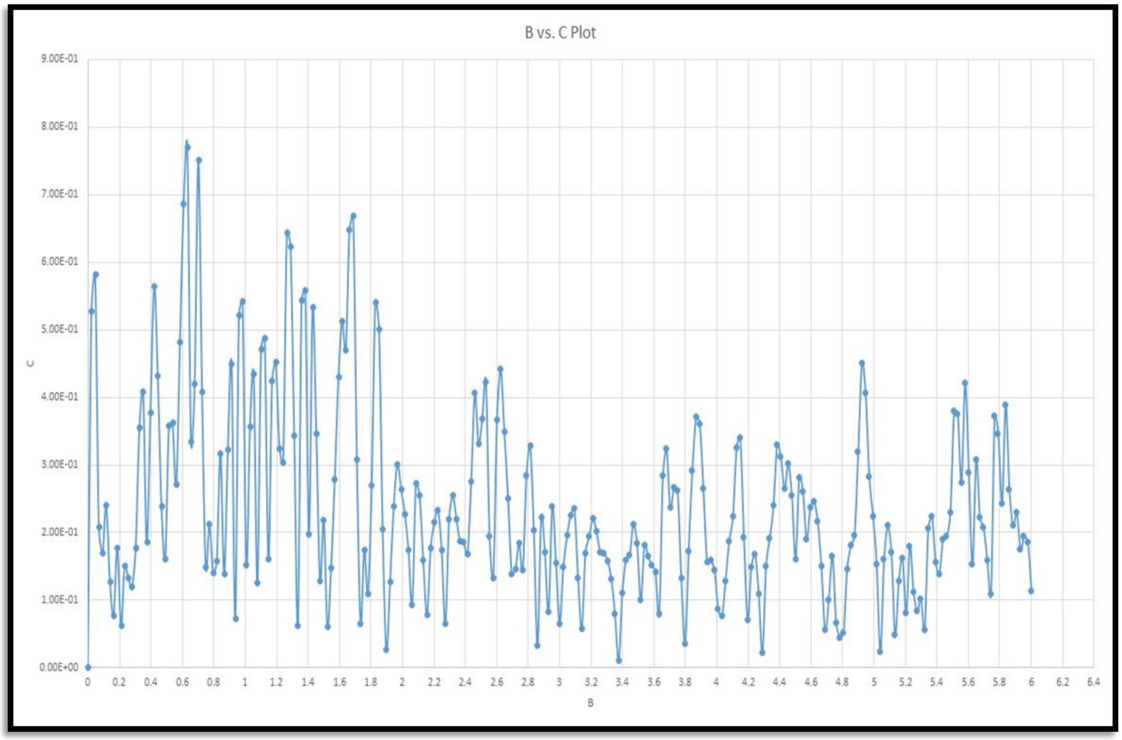

Figure 44. Fast Fourier transform plot

In Figure 44 the above plot, there is a noticeable peak cycle from 0.6-0.8 minutes. The second peak is at 1.6-1.8 minutes which leaves one minute interval between them. To understand this system, imagine a room as a system full of mass (air in this case). There is a source from where fresh air is pumped in the room.

For a balanced system, the air entering the system should be equal to the air dissipating, this would result in maintaining the pressure in the room. Failure to maintain this equilibrium would cause lower pressure being created in the room in some cases as shown above and the differential pressure would result in a cyclical formation.

CHAPTER V

CONCLUSIONS

This research continues a study into the movement of fungal spores into patient's rooms in hospital settings. The experimental work used the Langford Architectural Building A as a test case for this experimental system. The experimental work involved measuring the gaps around a 18 doors that were randomly selected in the building and then measuring the velocities on the gaps on all four sides.

The results show that the average largest gap occurs on the bottom of the door. The results show the highest velocity occurs on the bottom gap. The results shows for a 4 micron particle with a settling velocity of one millimetre per second in an air stream of 3.5 metres per second there is a tolerable probability that some particles will move under the door. The hypothesis is thus false. Dust on the floor can easily move beneath these doors.

One of the rooms, 107 on the ground floor exhibited very high velocities. A differential pressure study showed a cyclic pattern existed in the room with a cyclic frequency of about one minute. This suggests a tolerably high pressure cycle in the room.

Dust movement is a problem for nomosocial infections, this limited study points to the need for accurate and detailed work in a real hospital environment. Significant change will be required if nomosocial infections are to be reduced or eliminated.

One could argue that the contractors who build hospitals have a moral obligation to consider these matters during construction, as suggested by Donne.

Further work is recommended on measuring the dust movement beneath the door, and determining the cyclic pressure differentials within room 107.

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